A TEXT-BOOK

OF

DENTAL HISTOLOGY

AND

EMBRYOLOGY

INCLUDING

LABORATORY DIRECTIONS

BY

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THIRD EDITION, THOROUGHLY REVISED

WITH A CHAPTER ON THE ABSORPTION OF THE ROOTS OF TEETH

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WITH 343 ILLUSTRATIONS AND 21 PLATES

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To my Father

Dr. Edmund Noyes

Whose long and active professional career has been devoted,
without personal ambition or selfish advancement, to
the good of the Dental Profession, and whose
unselfishness and sacrifice have made
possible all that I have done
or may accomplish.

PREFACE TO THE THIRD EDITION.

THE exhaustion of the second edition of this work has afforded another opportunity for careful revision of the text and illustrations, and the addition of some important material, which has been developed since the appearance of the second edition. Many new drawings and a number of new micrographs have been prepared. The chapters on the lymphatics of the dental region and the absorption of the roots of teeth have been added, and the chapters on embryology, greatly enlarged.

The conditions at the present time, and especially the interest of the medical profession in the mouth as a source of systemie infection have put new emphasis on the teaching of histology, and have greatly changed the attitude of the dental profession. The need for a thorough knowledge of tissue structure and function is realized as it never has been before, and the demand for thorough training in the fundamental biological sciences has greatly increased.

The present interest and emphasis of the profession on the relation of the pulpless tooth to systemic diseases has somewhat changed the relative distribution of the text. The pages devoted to the enamel have been reduced, those devoted to the dentin, cementum and supporting tissues increased, and the chapter on the lymphatics added.

The work is primarily intended as an elementary text-book for dental students, rather than an exhaustive treatise on dental histology. For this reason, discussion of disputed ideas, presentation of various opinions, and reference to the work which has developed the subject have been largely and purposely avoided. It is the author's opinion that it is better for the student to get a clear idea of structure that he can use as a basis for thinking, rather than to be left with a hazy impression of differences of opinion.

In the preparation of this (the third) edition the author is specially indebted to Dr. Newton G. Thomas, who has prepared and written the chapter on the Absorption of the Roots of Teeth, and to Mrs. N. M. Frain, the artist for the department, who has made the illustrations.

F. B. N.

CHICAGO, 1921.

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INTRODUCTION.

The development in knowledge of the cell has had a most profound effect upon the entire practice of medicine; in fact, the progress of modern medicine has dated from the studies of cell biology, the germ theory of disease being only one of the phases of this development. In terms of the cell theory the functions of the body are but the manifest expression of the activities of thousands or millions of more or less independent but correlated centers of activity. If these centers or cells perform their functions correctly, the functions of the body are normal, but if they fail to perform their office or work abnormally, the functions of the body are perverted. In the last analysis, then, all physiology is cell physiology, all pathology cell pathology. To modern medicine, histology, or the cell structure of the organs and tissues of the body, together with cell physiology, is the rational foundation of all practice. This is as true for the dentist as for the physician in regard to the soft tissues of the mouth and teeth that he is called upon to handle. With caries of the teeth, the disease which most demands the attention of the dentist, the case is somewhat different. Caries of the teeth is an active destruction, by outside agencies, of a formed material which is the result of cell activity, the teeth themselves being passive. The cellular activities of organs and tissues of the body may have an influence, but this is only in producing those conditions of environment which render the activities of the destructive agent efficient in their action upon the tooth tissues. Though the dental tissues are passive, the phenomena of caries can only be understood when the structure of the tissues is understood, and not only must the treatment be based upon knowledge of the structure of the tissues, but the mechanical execution of the treatment is facilitated by that knowledge of structure.

In the preparation of cavities, the arrangement of the enamel wall is determined by the knowledge of the direction of the enamel prisms in that locality, and to a certain extent the position of cavity margins must be governed by the knowledge of the structure of the enamel. In the execution of the work a minute knowledge of the direction of enamel rods becomes the most important element in rapidity and success of operation. The longer the author studies and teaches the structure of the enamel in its relation to the structure and preparation of enamel walls, the more he finds himself using this knowledge at the chair in daily operations. He believes that nothing will do more to increase facility, rapidity, and success of operation than a close study of the enamel structure.

All tissues are made up of two structural elements—cells and intercellular substances. The cells give the vital characteristics, the intercellular substances the physical character. The cells are the active living elements, the intercellular substances are formed materials produced by the activity of the cells, and more or less dependent upon them to maintain their quality, but they possess no vital properties. They surround and support the cells, and the physical characteristics are given by them. An understanding of the relation of cells and intercellular substances in the structure and function of tissues is absolutely fundamental to the study of dental histology, and should be acquired in a thorough study of general histology before the subject is undertaken.

At the time the first edition of this work was prepared the relation of histologic structure of the enamel to the mechanical operation of dentistry was receiving special attention because of the study of cavity form for the prevention of the recurrence of caries, and the changes necessitated in cavity preparation because of this study. This phase of dental histology is just as important as ever, but it has been so generally accepted and so clearly grasped that now most of the applications in practice are taught, where they properly belong, in Operative Dentistry and the Technique of Cavity Preparation. In this edition, therefore, the space devoted to this subject is greatly reduced.

The problem of the pulpless tooth which now occupies the foremost place in the attention of the dental and medical professions emphasizes the importance of the histology of the dentin and cementum, and places new importance on the relation of cellular and intercellular substances in the tissue. For the dental student this subject should be given more careful consideration than is usual in elementary courses of general histology.

CHAPTER I.

HOMOLOGIES.

Exoskeleton.—In studying the organization of animal forms they are found, very early in the evolutionary stages, to develop some sort of a framework, or skeleton, to support and protect the creature. In the lower and earlier forms this framework is formed entirely of some sort of shell upon the outside of the creature, and consequently is called an exoskeleton. This may be either horny or chitinous in nature, as in the insects, crabs, etc., or it may be calcified, as in the shell-fish, or it may be both. The exoskeleton serves not only as a supporting framework, but also as a protection.

Endoskeleton.—In the higher forms an internal framework, or endoskeleton, is developed, which forms the scaffolding to support the creature, but does not act as a protection. In the first place, this is of cartilage, but may be changed into bone.

The exoskeleton is a product of the skin and may be of either epithelial or connective-tissue origin, or from both. The skin is made up of two parts: the epithelial covering or epidermis, and the supporting connective-tissue layer, or derma. Both layers take part in the formation of most exoskeletal structures. In the hair, the shaft is of epithelium, the bulb of connective tissue. In the tooth, the enamel is from the epithelium, the dentin, from connective tissue. In all bony structures belonging to the exoskeleton the bone is formed in fibrous tissue and is never preceded by cartilage. Bony structures belonging to the endoskeleton are formed from cartilage. In lower forms of animals they remain always cartilage. In man the cartilage is partly converted into bone, all of the bones of the endoskeleton being preceded by cartilage.

The first trace of the endoskeleton is found in the lowest form of vertebrate, the Amphioxus or Lancit, the lowest form of fish, and appears as a rod or notochord in the dorsal region. There is also an important difference in the nervous organization (Figs. 1 and 2). In the invertebrate the nervous system is represented by a larger or smaller ganglion in the anterior or head end, corresponding to the brain; this is dorsal to the alimentary canal. From this a ring passes around the anterior end of the alimentary canal

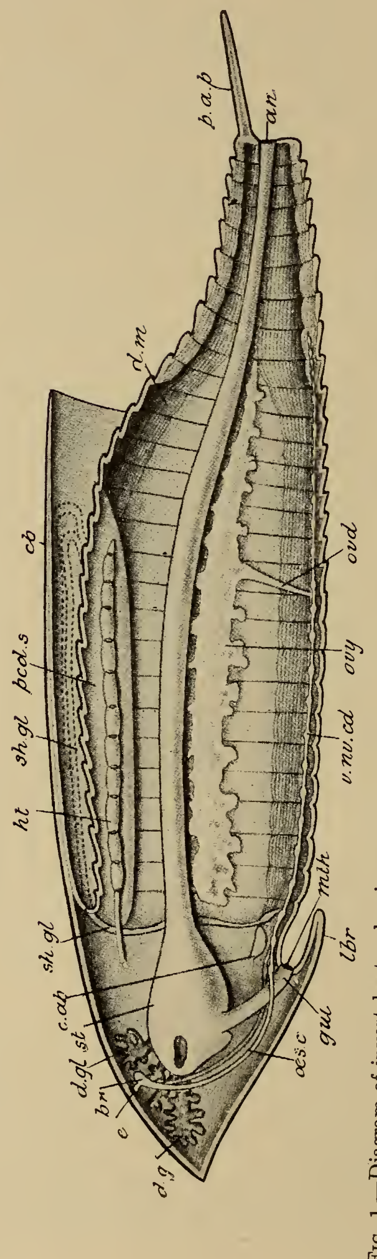


Fig. 1.—Diagram of invertebrate, showing nervous system. (Parker and Haswell.) Lepiduras kirkii, sagittal section: *an*, anus; *br*, brain; *c.ap*, cephalic apodeme; *cb*, carapace; *d.gl*, digestive gland; *d.m*, dorsal muscle; *e*, median eye; *gul*, gullet; *ht*, heart; *lbr*, labrum; *mth*, mouth; *œs.c*, esophageal connective; *ovd*, oviduct; *ovy*, ovary; *p.a.p*, postanal plate; *pcd.s*, pericardial sinus; *sh.gl*, shell gland; *v.nv.cd*, ventral nerve cord.

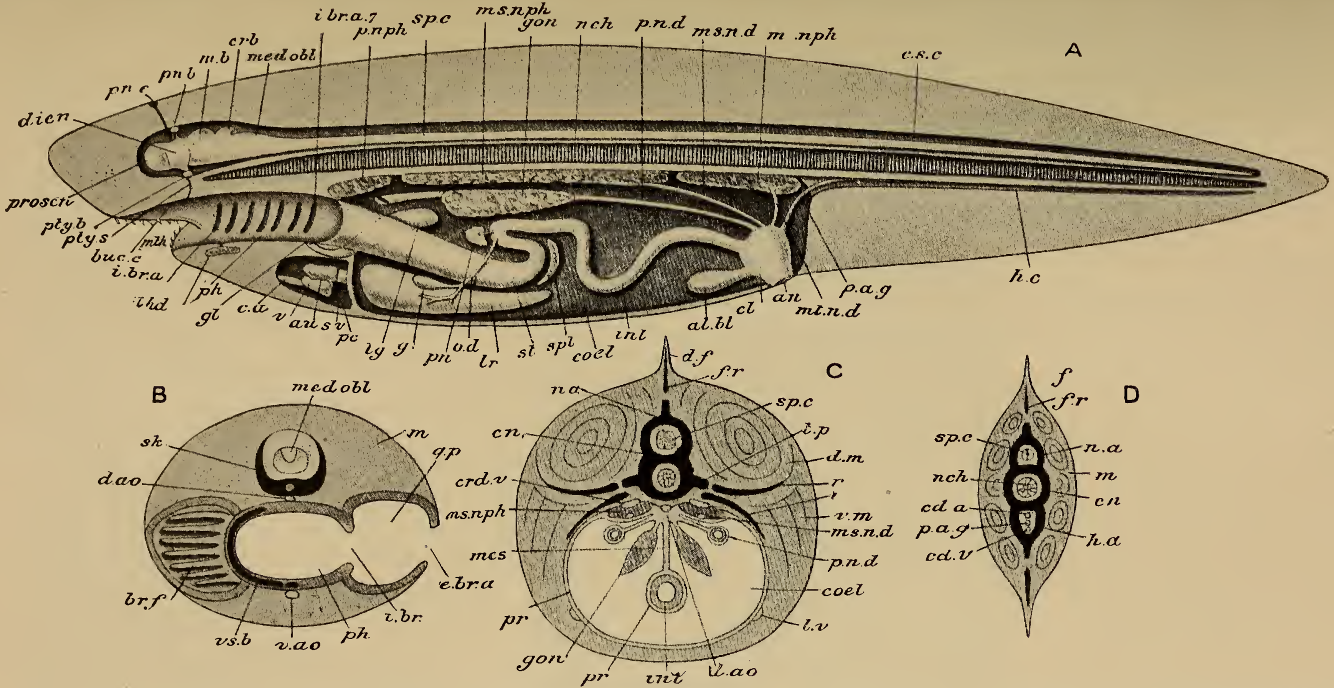


Fig. 2.—*A*, sagittal section of ideal craniate; *B*, transverse section of the head; *C*, of the trunk; *D*, of the tail; *al.bl*, allantoic bladder; *an*, anus; *au*, auricle; *b.d*, bile duct; *br.f*, branchial filaments; *buc.c*, buccal cavity; *c.a*, conus arteriosus; *cd.a*, caudal artery; *cd.v*, caudal vein; *coel*, celome; *crd.v*, cardinal vein; *cn*, centrum; *crb*, cerebellum; *c.s.c*, cerebrospinal cavity; *d.ao*, dorsal aorta; *dien*, diencephalon; *d.f*, dorsal fin; *d.m*, dorsal muscles; *e.br.a*, external branchial aperture; *f.r*, fin-ray; *g.b*, gall-bladder; *gl*, glottis; *gon*, gonad; *g.p*, gill-pouch; *h.a*, hemal arch; *h.c*, hemal canal; *i.br.a*, internal branchial apertures; *int*, intestine; *lg*, lung; *lr*, liver; *l.v*, lateral vein; *m*, muscles; *m.b*, midbrain; *med.obl*, medulla oblongata; *mes*, mesentery; *ms.n.d*, mesonephric duct; *ms.nph*, mesonephros; *mth*, mouth; *mt.n.d*, metanephric duct; *mt.nph*, metanephros; *n.a*, neural arch; *nch*, notochord; *p.a.g*, postanal gut; *pc*, pericardium; *ph*, pharynx; *pn*, pancreas; *pn.b*, pineal body; *p.n.d*, pronephric duct; *pn.e*, pineal sense-organ; *p.nph*, pronephros; *pr*, peritoneum, parietal layer; *pr'*, visceral layer; *prosen*, prosenchephalon; *pty.b*, pituitary body; *pty.s*, pituitary sac; *r*, subperitoneal rib; *r'*, intermuscular rib; *sk*, skull; *sp.c*, spinal cord; *spl*, spleen; *st*, stomach; *s.v*, sinus venosus; *thd*, thyroid; *t.v*, transverse process; *v*, ventricle; *v.ao*, ventral aorta; *v.m*, ventral muscles; *vs.b*, visceral bar. (Parker and Haswell.)

and unites with a chain of ganglia ventral to it. The nervous system of the invertebrate then is, with the exception of the brain ganglia, ventral to the alimentary canal, and corresponds to the sympathetic system in higher animals. It will be noted that this arrangement puts the nervous system, which controls the activity of the individual, in the most protected position. The invertebrate crawling upon the ground is subject to attack or injury from above, but it may be cut almost in two before the nervous system is reached.

In the vertebrate the central nervous system appears as a chain of ganglia dorsal to the alimentary canal and notochord (Fig. 2). This difference is significant, and may be expressed roughly in this way: The invertebrate framework is an outside protecting shell, upon which the creature depends for protection. The vertebrate framework is an internal structure to facilitate motion and give support, and is accompanied by a development of the nervous organization, so that the creature protects itself by more rapid motion. In the invertebrate the digestive system is above or dorsal to the nervous system, in the vertebrate the nervous system is in the upper position, both structurally and functionally.

In ascending in the scale of organization the endoskeleton increases in importance and development, while the exoskeleton decreases in importance and development.

From the standpoint of comparative anatomy the teeth are not a part of the osseous system, but appendages of the skin, and are to be compared with such structures in the body as the hair and the nails. The teeth are a part of the exoskeleton, and their relation to the bones is entirely secondary for the purpose of strength, the bone growing up around the tooth to support it.

Placoid Scales.—In the skin of such fishes as the shark and the dog-fish small calcified scales are found, which are made up of a conical cap of calcified tissue like enamel, resting on a cone of dentin which contains a vascular core or pulp. These are surrounded by a basal plate of tissue like cementum into which the fibers of the derma are imbedded. Only the tips of these scales project through the skin. These are the structures from which the teeth have been derived in evolution.

From the standpoint of development the mouth cavity is to be regarded as a part of the outside surface of the body which has been enclosed by the development of neighboring parts, and the dermal scales, or rudimentary teeth, which are found in the skin covering the arches forming the jaws, have undergone special development for the purpose of seizing and masticating the animal's food. In the simplest forms there is only a development in size and shape of these scales, and they are supported only by the connective tissue which underlies the skin. These teeth are easily torn off in the attempt to hold a resisting prey, and in the shark (Fig. 3) they are continually being replaced by new ones. In the more highly developed forms the bone forming the jaw grows upward around the bases of these scale-like teeth to support them more firmly and render them more useful.

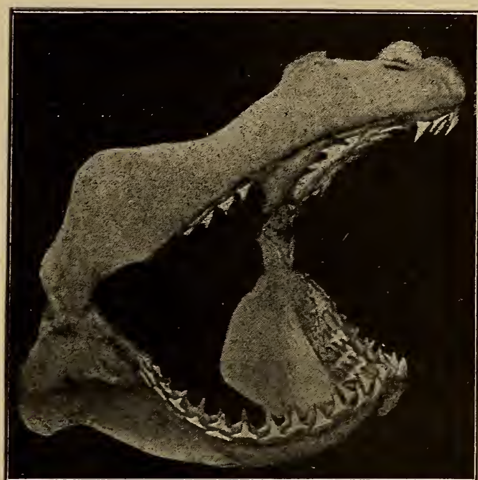


Fig. 3.—Shark's skull (Lamna cornubica), showing succession of teeth.

Homology and Analogy.—In biology structures that are similar in formation and origin are called *homologous*. Structures that are similar in function are called *analogous*. A structure or organ may be both homologous and analogous to another, but not necessarily so. For instance, the wing of a fly is analogous to the wing of a bird, because they are used for the same purpose, but they are not homologous. The wing of a bat and the wing of a bird are both analogous and homologous, being used for the same purpose, and having similar structure and origin. The arm of man is homologous to the wing of a bird, but not analogous to it. The jaws of a crab or beetle are analogous to the jaws of man, but they are not homologous structures, as the jaws of the crabs and insects are modified legs. The teeth are said to be homologous to the dermal scales of certain fishes, and to the appendages of the skin, such as the hair and nails, because they are similar in structure and origin (Plate I).

Comparison of Structure.—If the tooth is compared with the hair in this way this will be better understood. The hair may be considered as a *horny structure composed of* epithelial cells resting upon a papilla of connective tissue. The tooth may be considered a calcified structure, *formed by epithelial* cells, resting upon a papilla of connective tissue, which is also *partially calcified.*

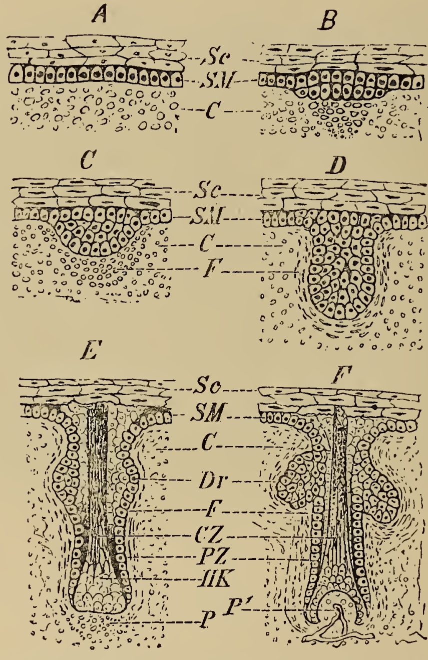
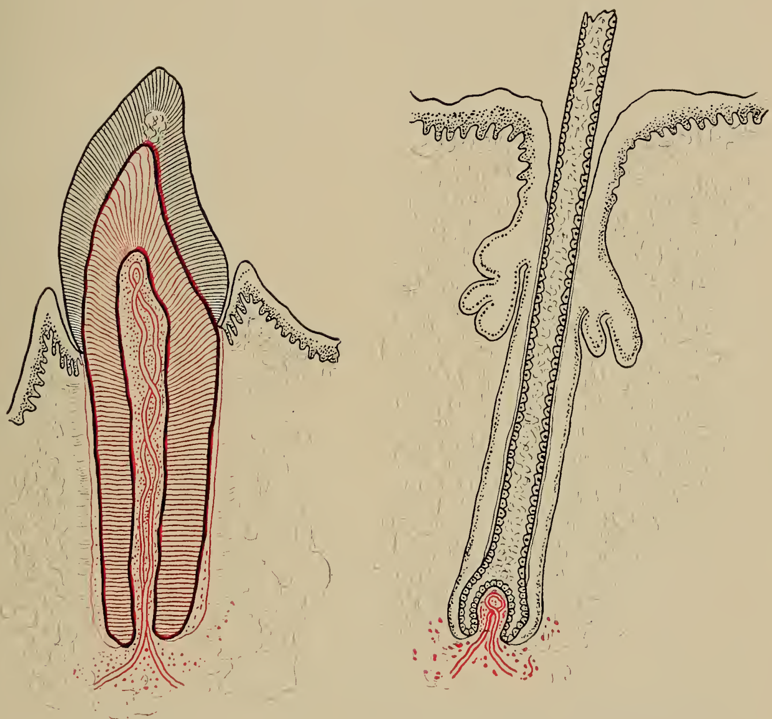


Fig. 4.—Development of the hair: *Sc*, stratum corneum; *SM*, stratum malpighii, *C*, derma; *Dr*, sebaceous gland; *F*, follicles; *CZ*, central, *PZ*, peripheral zone of hair germ; *HK*, hair knob; *P*, beginning the formation of the 'hair papilla; *P′*, same in a later stage of development when it has become vascular. (Wiedersheim, *Comparative Anatomy of Vertebrates.*)

Comparison of Origin.—From a study of the development of the tooth and the hair, the similarity of their origin and structure becomes more apparent.

The first step in the development of the hair is a thickening of the epithelium at a point, the epithelial cells multiplying and growing down into the connective tissue below, so as to make a two-

PLATE I



Comparison of Structure of Tooth and Hair.

layered bag or cap, the connective tissue growing up in the form of a cone-shaped papilla into the cavity of the cap (Fig. 4). The epithelial cells of the inner layer, next to the connective tissue, multiply rapidly and develop horny material and are pushed out from the surface of the skin as the shaft of the hair.

In the development of the tooth there is at first a thickening of the epithelium, and a mass of epithelial cells like that forming the hair, but larger, grows down into the connective tissue (Fig. 5). This becomes bulbous, then invaginated, forming a two-layered

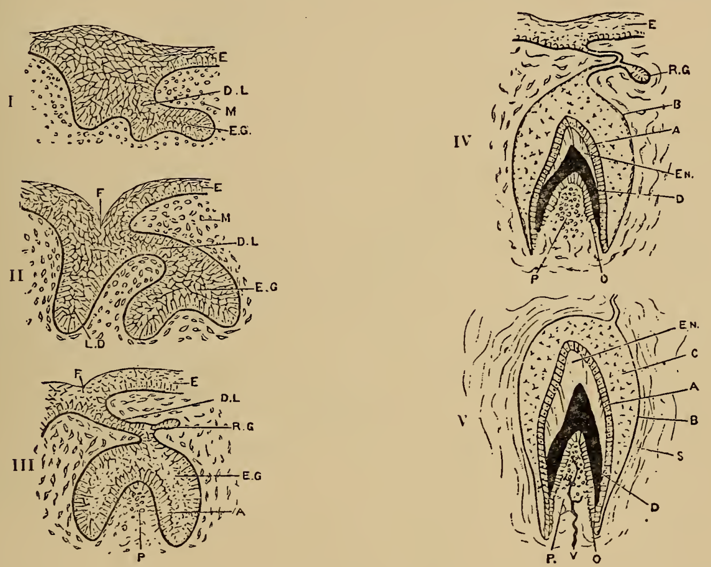


FIG. 5.—Diagram to illustrate development of a tooth; *A*, inner layer of enamel germ; *B*, outer layer; *C*, remains of intermediate cells; *D*, dentin; *DL*, dental lamina; *E*, epithelium; *E.G*, enamel germ; *En*, enamel; *F*, dental furrow; *L.D*, labiodental furrow; *M*, connective-tissue cells; *O*, odontoblasts; *P*, dentin papilla; *R.G*, reserve germ; *V*, bloodvessel. (Cunningham's *Anatomy.*)

cap. The two layers are at first perfect and are farther from the surface than the epithelial structure which develops the hair. A cone-shaped papilla of connective tissue, the dental papilla, grows up into the cavity of the epithelial organ corresponding to the bulb of the hair.

The inner layer of epithelial cells produce the enamel, the outer layer of connective-tissue cells, covering the connective-tissue papilla, develop the dentin, leaving the pulp inside as the remains of the dental papilla.

Phylogeny is the history of the development or evolution of the species. *Ontogeny* is the development of the individual. In homologous structure we may trace the similarity in their origin, both in

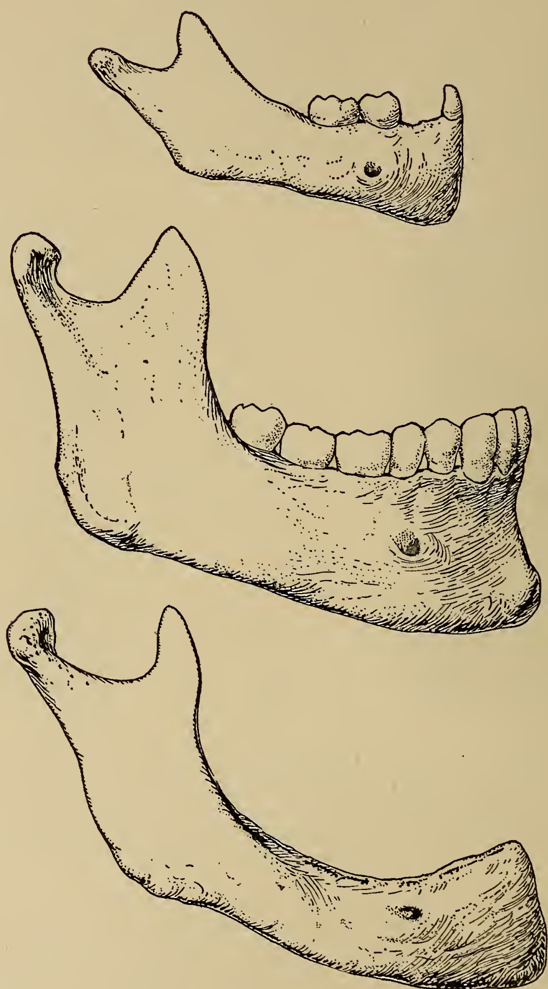


Fig. 6.—Changes in the mandible with age; buccal and lingual view.

ontogeny, or the development of the individual, and in phylogeny, or the development of the species.

Relation to the Bone.—The relation of the bones of the jaws to the teeth is entirely secondary and transient. The bone grows up around the roots of the teeth to support them, and is destroyed and removed with the loss of the teeth or the cessation of their function. In this way the development of the alveolar process appears around the roots of the temporary teeth. All this bone surrounding their roots is absorbed and removed with the loss of the temporary dentition, and a new alveolar process grows up around the roots of the permanent teeth as they are formed. This development of bone around the roots of the teeth leads to the changes in the shape of the body of the lower jaw, increasing the thickness from the mental foramen and the inferior dental canal upward (Fig. 6). When the teeth are finally lost this bone is again removed and the body of the jaw is reduced in thickness from above downward. These phenomena have an important bearing upon the causes and treatment of diseased conditions of the teeth, particularly those which involve the supporting tissues.

From the dental standpoint it is important to note that the teeth are formed first and the bone is developed to support them. The use of the teeth through occlusion reacts upon the formation of bone. The study of anatomy, as well as direct experiment, has shown that muscular function, acting through occlusion, affects the development, not only of the bone of the alveolar process, jaws and face, but of the entire skull. It is most important for the student to realize that the teeth are moving with reference to the skull as a whole, through the entire period of development, and, in fact, throughout life.

CHAPTER II

THE DENTAL TISSUES.

Study of the structure of the teeth shows that all teeth,[1] from the simplest to the most complex, are composed of but four tissues—enamel, dentin, cementum, and the pulp, or formative tissue of the dentin. All teeth are maintained in position and rendered functionally useful by certain supporting tissues.

Even the simplest placoid scales, as found in the skin of the shark and dog-fish, contain these four tissues. In many of the specialized forms of teeth some of these tissues may be absent. For instance, in the bony fishes the teeth are fastened to the bone by an interlocking of bone and dentin, forming an ankylosed attachment, and the cementum is absent; but in some of these there is also a slight formation of cementum. In the tusks of elephants during the functional period the dentin is not covered by enamel, but when the tusk first erupted there was a slight enamel cap, which was at once broken or worn off. In many instances the enamel seems to be entirely absent, and for that reason it has sometimes been called the most inconstant of the dental tissues, but in every case in which the development of the tooth has been studied an enamel organ has been found. It is probably much more nearly correct to consider that in all cases enamel is formed, but that it may be so thin and transparent as to be very difficult to recognize, and very soon may be entirely lost.

FUNCTIONS OF THE DENTAL TISSUES.

The Enamel.—The enamel forms a hard protecting surface or cap especially adapted to resist abrasion. It is the hardest animal tissue, but brittle and inelastic, and dependent upon the support of the elastic dentin for strength. Its function is to resist the abrasion of friction. Its arrangement in many instances is found specially modified for this purpose.

[1] The formation of a satisfactory definition of a tooth is by no means an easy matter. The word here is used to mean teeth that are derived in the phylogenetic series from the placoid scale, as the starting-point of evolution.

The Dentin.—The dentin is the strong elastic tissue forming the great mass of the tooth, and gives to it its strength. Teeth that are subjected to stress and force are often made up of dentin without enamel. If, for instance, the tusks of the elephant, used for such purposes as tearing down branches, spading up the ground, and so on, were made up entirely of enamel, they would break off the first time they were locked in the branches or driven into the ground, but the elastic dentin gives and bends and will stand great stress. The teeth of many animals which use their tusks in fighting are constructed on the same plan. Such tusks usually have an enamel cap when they first erupt, and in every case an enamel organ is present in the tooth germ.

The Cementum.—The cementum furnishes attachment for the connective-tissue fibers which fasten the tooth to the bone or surrounding tissues. It is formed on the enamel and dentin both before and after the eruption of the teeth but only on portions embedded in the tissues at the time of formation. The formation of the cementum on the surface of the root fastens the surrounding connective-tissue fibers to the tooth. The fibers are calcified along with the matrix of the cementum which is built up around them. These fibers in man and the higher animals extend to the bone and the surrounding tissues and support the teeth against the forces of mastication and hold the surrounding tissues in proper relation to the teeth. The function of the cementum is therefore to attach the connective-tissue fibers to the surface of the root.

The Pulp.—The pulp is the remains of the formative organ of the dentin. In teeth of continuous growth it remains actively functional throughout the life of the tooth, but in teeth of limited growth, after the typical development of dentin, it becomes functional again only in response to irritations which, however, may be local or reflex. The pulp performs two functions—a *vital* function, the formation of dentin, and a *sensory* function, the response to thermal change.

Summary.—The dental tissues, *i. e.*, enamel, dentin, cementum, and pulp, are so called not simply because they are found in the human teeth, but because all teeth are composed of these four tissues.

It is true that in comparative dental histology considerable difference exists in the microscopic structure of these tissues from the teeth of different animals, but certain characteristics are very persistent and quite characteristic of each.

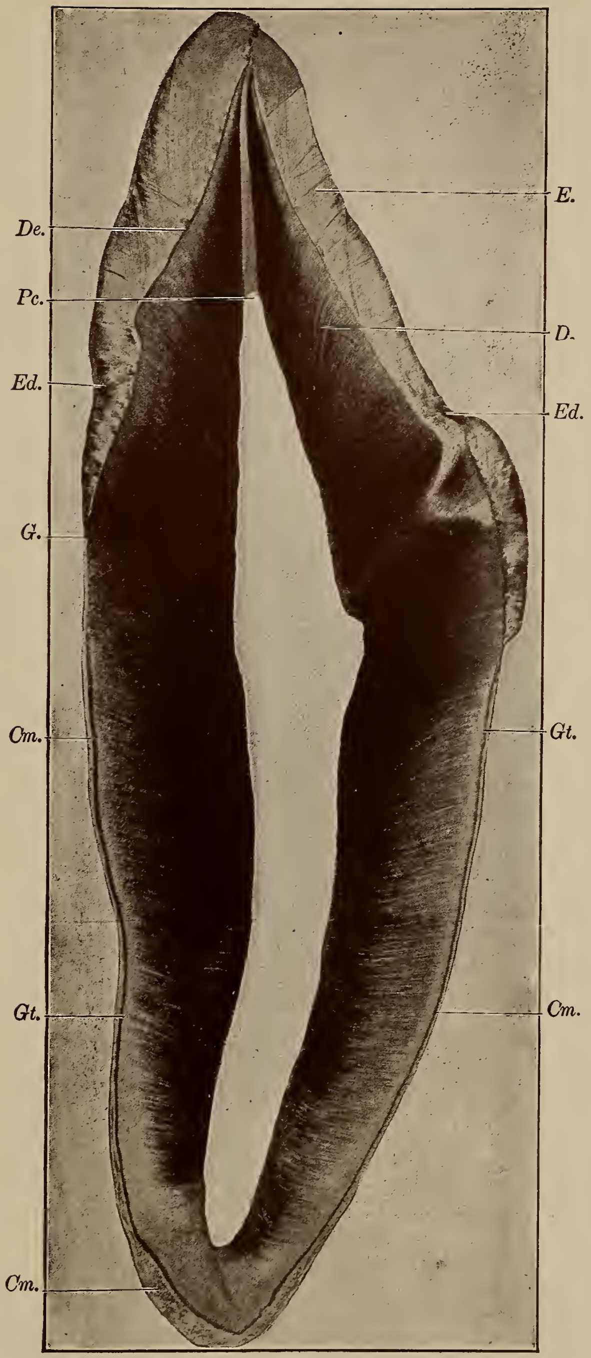
DISTRIBUTION OF THE DENTAL TISSUES.

The arrangement and distribution of the dental tissues in the structure of the human teeth is best studied in ground sections cut longitudinally through the entire tooth (Plate II), and series of transverse sections cut through the roots. For this purpose the sections should not be too thin (from 10 to 20 microns). For the study of the arrangement of the cementum and dentin in the roots at least three transverse sections should be ground from each root, one from the gingival, one from the middle, and one from the apical third.

The Enamel.—The enamel forms a cap over the exposed portion of the tooth. Its function is to resist the abrasions of mastication. It gives the detail of crown form to the tooth. It extends to the gingival line, and, except in old age, is covered in the gingival portions by the epithelium of the gingivæ which lies in contact with it but is not attached to it. It is thin in the gingival portion and is normally overlapped slightly by the cementum at the gingival line. It extends farther apically on the labial and lingual, and buccal and lingual, than upon the proximal surfaces, especially on the incisors, cuspids, and bicuspids. It is thickest in the occlusal third of the axial surfaces, and on the occlusal surfaces of the molars and bicuspids, especially over the cusps. In the incisors and cuspids it is thickest in the occlusal third on the labial and over the marginal ridges on the lingual. The dento-enamel junction, though not parallel with the surface of the enamel is usually curved in the same direction except near the cusps in molars and bicuspids, where the curve is sometimes reversed, apparently to give greater thickness of enamel where resistance to wear is most needed.

In the molars and bicuspids the dento-enamel junction in the occlusal thirds on the buccal and lingual is usually curved in the opposite direction. That is, while the surface of the enamel is convex, the surface of the dentin is concave. It will be seen that this not only gives a greater thickness to the enamel in the region which will resist abrasion, but also gives it a firmer seat upon the dentin. (Study illustrations in Chapter IX.) The dento-enamel junction is seldom a smooth, even surface, but will appear scalloped in sections, projections of dentin extending between projections of enamel (Fig. 7). In three dimensions this means that rounded projections of the enamel rest in rounded depressions of the dentin surface, and pointed projections of the dentin extend between the

PLATE II



Ground Section of a Canine.

E, enamel; *Cm*, cementum; *D*, dentin; *Pc*, pulp chamber; *De*, dento-enamel junction; *Ed*, enamel defect; *G*, junction of enamel and cementum at the gingival line; *Gt*, granular layer of Tomes. (Reduced from a photomicrograph made in three sections.)

rounded projections of the enamel. This is similar but much less marked than the interlocking of the papilla of connective tissue with the projections of the Malpighian layer of stratified squamous epithelium of the skin and mucous membrane. In some cases these

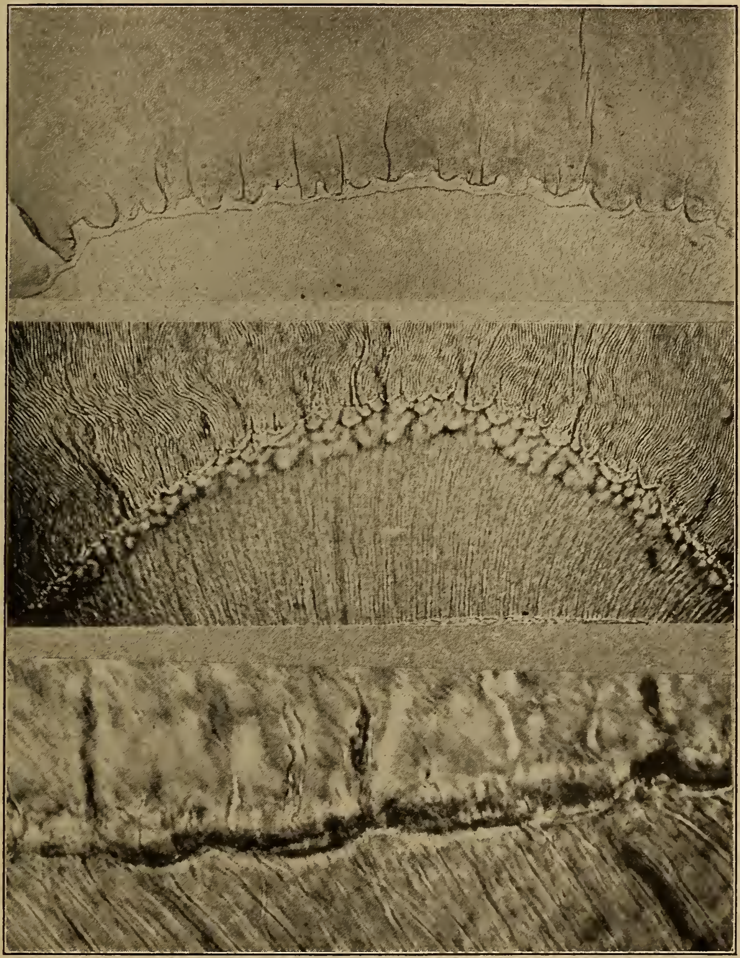


FIG. 7.—Dento-enamel junction.

projections of dentin into the enamel may be quite marked. This scalloping of the dento-enamel junction gives a stronger attachment of the enamel to the dentin, and accounts, partially at least, for the difference that is observed in the ease with which enamel can be removed from the dentin in the preparation of roots for crowns. Where the two tissues join with smooth surfaces the enamel can be comparatively easily cleaved away; where the scalloping is marked it is removed with much greater difficulty.

The Dentin.—The dentin gives the strength to the tooth. This should never be lost sight of in operations, and sound dentin should always be conserved to the greatest possible extent in the preparation of cavities. That the function of the dentin is to give strength will be seen more clearly from a comparative study of teeth modified for special functions. The dentin forms the greatest mass of the tooth, the type form being determined by it. The cusps and ridges, although different in form, are still represented in the dentin as well as the number and shape of the roots, while the detail of the form of the roots is modified by the addition of the cementum on the surface.

The dentin forms a layer of comparatively even thickness surrounding the central cavity or pulp chamber, which is occupied by the formative organ. From this cavity a great number of small tubules extend through the calcified dentin matrix to the surface under the enamel and cementum. In the crown portion the course of these tubules is characteristically curved like the letter *S* or *f*, so that the tubules tend to enter the pulp chamber at right angles to the surface and to end under the enamel at right angles to the dento-enamel junction (Plate II). On closer study these tubule directions will be found to be more complicated, but in studying the distribution of dentin they should be noted. In the root portion the tubules are usually comparatively straight, that is, without the double curve, and are at about right angles to the axis of the canal.

The outer layer of dentin under low magnification presents a peculiar granular appearance, which is specially apparent under the cementum. This is known as the granular layer of Tomes, and is caused by irregular spaces in the dentin matrix which communicate with the dentinal tubules.

The Cementum.—The cementum covers the dentin in the root portion, and in most cases slightly overlaps the enamel at the gingival line. This is not always true, for in some cases it just meets the enamel, and in others there is a space where the dentin is uncovered between the enamel and the cementum (Fig. 8). It has not been positively determined whether this can ever be considered a normal condition, and the author has some reason to suppose that the sections showing this condition were from teeth from which the gums had receded and the cementum was destroyed. The sensitiveness which is so marked in some cases, where the gums have receded beyond the gingival line, is probably due to the loss of cementum and the uncovering of the granular layer of Tomes.

The cementum is thin and structureless in appearance in the gingival portion when viewed with low powers, but becomes thicker

Fig. 8.—Gingival line, showing the relation of enamel and cementum.

in the apical third. In the thicker portions irregular spaces (lacunæ) with radiating canals (canaliculi) are seen. In life these spaces contain living cells (the cement corpuscles), which correspond to the bone corpuscles found in the lacunæ of bone. Upon the convex surfaces of the root the cementum is thin; upon the concave surfaces it is thicker. This increases with age, and so the continuous formation of cementum tends to round the outlines of the roots and to unite them where they approach each other. The fibers which are built in the cementum are often imperfectly calcified, especially where the layers are thick, so that in the ground sections they may often be easily mistaken for canals, because the imperfectly calcified fiber has shrunk in the preparation.

ADAPTATION IN THE DISTRIBUTION OF DENTAL TISSUES.

If the teeth of mammals are studied in a comparative way many modifications will be found in the relative amount and distribution of the dental tissues, adapting the tooth to perform special functions. A study of these modified or specialized teeth will give a better understanding of the functions of the tissues in the tooth. The human tooth may be taken as a type of omnivorous tooth, and the arrangement and distribution of its tissues has already been described.

Teeth of Continuous Growth.—In many animals the teeth or some special teeth are developed as weapons, or as implements to aid in securing food. It is usually the cuspid teeth that show this modification, as in the tusks of the boar and many species of the carnivora, the tusks of the walrus, and other examples. In the case of the elephant the incisors have been developed in the same way. Whenever the teeth have been developed in size for uses which require strength and the ability to withstand stress and strain, the increase in size is by development of the mass of dentin, the enamel often being entirely lost during the functional period. If these teeth were composed chiefly of enamel they would be too brittle. These tusks, which, as in the case of the elephant, sometimes reach a weight of many hundreds of pounds, are usually deeply embedded in the bone, and the concealed portion is covered with a layer of cementum which attaches the fibers, holding them to the bone, but they retain a conical pulp in a cone-shaped pulp chamber at the base of the tooth, which continues to form dentin. The tooth is pushed out of the socket, as the shaft of the hair is pushed out, by the multiplication of cells covering the bulb. In this way the size of the tooth is maintained as the exposed and functional part is worn off. Strength and elasticity are required, therefore the dentin is developed. The cementum which is formed on the embedded portion for attachment of fibers is worn off as soon as it is exposed to friction.

Chisel Teeth.—The incisors of the rodents, as rats, mice, squirrels, and beavers, present an interesting modification for a special function. These teeth are used as chisels for cutting hard substances, as wood, shells of nuts, etc. Here strength and hardness are required. The dentin is increased by the continual function of a conical persistent pulp which continues to form dentin, and the enamel organ is carried down into the socket, to the base of the dental papilla, on the labial, instead of stopping at the gingival line, as in the human incisors. In this position it continues to build enamel on the labial side of the dentin. The enamel rods, instead of being straight, are twisted about each other in a complicated fashion, giving the maximum of hardness. As the incisors work against each other by the movements of the jaw, the dentin is worn off on the lingual side and the enamel kept in the form of a chisel edge. There is also a modification of the temporomandibular articulation, allowing the lower jaw to move forward and back as well as up and down, but not laterally, so that the lower incisors can be closed either lingually or labially to the upper, and in this way both the upper and the lower incisors are made to sharpen each other in use. In this case there is need for both strength and hardness, and both dentin and enamel are continuously being formed at the base of the tooth embedded in the socket, and the cementum is formed over the embedded portions as the medium of attachment.

Grinding Teeth.—In a grinding tooth, as in the molar of the horse and cow, and in a much more complicated form in the elephant, the three tissues—enamel, cementum, and dentin—are arranged so as to form, by the different rapidity of abrasion, corrugated grinding surfaces like millstones. The conditions can be understood if it is remembered that the cusps in the dentin are very high, and are covered by a comparatively thin layer of enamel. After the enamel is formed, and while the tooth is embedded in its crypt in the bone, cementum is formed, covering the surface and filling up the hollows between the cusps, so that the crown when it first erupts is rounded, with enamel showing only at the tips of the cusps. As soon as the tooth wears, the tip of the enamel is worn through, so that the circumference of the crown shows first cementum, then enamel, then dentin, then enamel, then cementum, then enamel, and so on. The foldings of the enamel often become very complicated, but the most complicated forms can be understood in this way.

Descriptive Terms.—In describing the structure of the teeth and the arrangement of the structural elements of the tissues, directions are described with reference to three planes: The mesiodisto-axial plane passing through the center of the crown from mesial to distal and parallel with the long axis of the tooth.

The bucco-linguo-axial plane, a plane passing through the center of the crown from buccal to lingual and parallel with the long axis of the tooth.

The horizontal plane at right angles to the axial planes.

CHAPTER III.

THE ENAMEL.

Enamel may be defined as the hard, glistening tissue covering the crowns of the teeth in man and most mammals. It is the hardest animal substance and contains less organic matter than any other tissue of the body.

Histogenesis.—The enamel is formed by the epithelial cells of the inner tunic of the enamel organ. After the tissue is formed the cells which produced it are destroyed and the tissue is left as a formed material covering the dentin.

Structural Elements.—The enamel is composed of two structural elements: (1) The enamel rods, or prisms. (2) A calcified substance which unites the rods into a continuous structure called the cementing, or interprismatic substance.

The enamel differs from all other calcified tissues:

1. In origin.
2. In degree of calcification.
3. In relation to its formative organ.
4. In the form of the structural elements of the tissue.

It is well to emphasize these points of difference, for throughout dental and medical writing, reasoning by analogy from bone conditions to tooth conditions, and especially to changes in the enamel, is often found. For instance, the argument has been made that because there may be changes in the bones in pregnancy, "softening" of the teeth would be expected. Many similar, though less crude, arguments would not be made if it were remembered that histologically, histogenetically, physiologically, and morphologically the enamel stands *alone.*

Origin.—The enamel is the only calcified tissue derived from the epithelium. All other calcified tissues are connective tissues. Histogenetically, then, the enamel is ultimately derived from the epiblastic germ layer, while all other calcified tissues arise from the mesoblast. Thus, even at the first step in the differentiation of the cells, enamel is different and independent from bone, cementum, or dentin. It is natural, therefore, to find the enamel differing from bone in every other respect. On the other hand, the relation of the enamel to the epithelium becomes more and more apparent. For instance, imperfections in the structure of the enamel during its formation are most likely to be produced by systemic conditions which affect the epithelium. The eruptive fevers occurring during enamel formation often produce imperfections of structure. Scarlet fever is most pronounced in its epithelial effect, causing loss of skin, loss of living epithelium of the alimentary tract, and often loss of hair, and is likewise most likely to produce pitted teeth or hypoplasia of the enamel. In other words, the same poison which is produced by the germ of scarlet fever causes the death of epithelial cells, of the skin, of the hair bulb, of the mucous membrane, and of the enamel organ.

The most recent work of Dr. Black shows the brown and mottled enamel of certain localities to be found associated with greatly freckled skin. Enamel therefore must be considered as epithelial in origin and ultimately from the epiblast, while all other calcified tissues are connective tissue and ultimately of mesoblastic origin.

Degree of Calcification.—The enamel is by far the hardest animal tissue. Chemically it is composed of water, calcium phosphate, carbonate, and a small amount of fluoride, magnesium phosphate, and a trace of other salts. Normally it should contain no organic matter. Von Bibra gives the following analysis:

Calcium phosphate and fluoride	89.82
Calcium carbonate	4.37
Magnesium phosphate	1.34
Other salts	0.88
Cartilage	3.39
Fat	0.20

It is very difficult to obtain enamel for chemical analysis entirely free from dentin, and small portions of dentin clinging to it are probably responsible for some of the organic matter given in the above analysis.

In all the older analyses the enamel was said to contain 95 to 97 per cent. of inorganic matter and 3 to 5 per cent. of organic matter, while the percentage in dentin was given as 72 per cent. of inorganic and 28 per cent. of organic, and in bone as 68 per cent. inorganic and 32 per cent. organic (dry compact bone). This in itself shows an enormous difference in the degree of calcification between enamel and the other hard tissues, but the results of more recent work are still more remarkable. In most of the original studies of the chemical composition, the enamel was broken into small pieces and dried for some time at a temperature above the boiling-point of water, to drive off all the moisture. The dry enamel was weighed and then ignited, and the loss in weight taken as the amount of organic matter. In 1896 Mr. Charles Tomes,[1] of London, published the results of his chemical analysis of enamel in which he showed that a large part of the loss of weight in ignition was due to the loss of water. He carried out ignition in tubes to collect the products of combustion, and found that between red and white heat from 2 to 3 per cent. of water was given off. This occurred suddenly and with almost explosive violence, blowing large pieces to fragments. While this did not account entirely for all of the matter previously considered organic, the character of the product of combustion and the observation of the material during ignition led him to conclude that the remaining portion was due to the dentin adhering to the enamel, and that the enamel contained not more than a trace of organic matter.

Dr. Leon Williams attacked the problem from the microscopic and microchemical side, and was forced to the conclusion that normal enamel contains no organic matter. No trace of organic matter can be found in sections of enamel by staining. And if the enamel is dissolved by acid and the progress observed, not a trace of organic matrix can be found. The conclusion is therefore imperative that enamel is composed entirely of inorganic matter, which has been deposited and calcified in the form of the tissue by the formative cells. In other words, enamel is formed material produced by cells and laid down in a definite structure, but it contains no organic matrix, while all other calcified tissues are composed of an organic matrix of ultimate fibrous and gelatin-yielding character, in which inorganic salts are deposited in a weak chemical combination, and living cells are retained in spaces of the formed material.

If bone or dentin is subjected to the action of acid, the combination between the organic and inorganic matter is broken up and the inorganic matter dissolved, leaving the organic portion, which yields gelatin when boiled in water, in the form of the original tissue. If enamel is treated with acid the cementing substance between the rods is first attacked and is dissolved more rapidly, then the rods are attacked from their sides, and finally the tissue is entirely destroyed, leaving no trace of structure. Apparently the greater the dilution of the acid the greater will be the extent

[1] Journal of Physiology.

of the solution of the cementing substance before the rods are destroyed.

If bone or dentin is burned or ignited, the organic matter will be driven off and the inorganic portion will be left in the form of the tissue, still showing its structure. If enamel is ignited, water of combination and whatever foreign matter has clung to the pieces is given off, but the form of the tissue is unchanged. To illustrate the difference by a crude comparison: Bone matrix may be likened to a piece of cloth into which inorganic salts have been deposited until it has become stiff and rigid, but the web of the cloth is still seen. The salts may be dissolved out and the cloth left, or the cloth may be burned out and the salts left. The enamel may be compared to a fossil in which, by molecular change, the organic matter has been removed and inorganic matter substituted, so that no organic matter remains, but the structure is preserved. If the inorganic salts were dissolved, no trace of structure would remain. On the other hand, by ignition, nothing but water can be driven off.

Relation to the Formative Tissue.—The enamel is produced by epithelial cells, which are lost and destroyed after the tissue is completed. Any such thing, therefore, as a vital change in the tissue is biologically unthinkable. After the enamel is formed it can be changed only by chemical and physical action of its environment.

All other calcified tissues are formed by connective tissue, and remain in vital relation with connective tissue of undifferentiated character. Bone and dentin matrix are therefore simply calcified intercellular substances containing living cells in the spaces of the matrix which maintain its chemical quality. A change in the character or amount of the matrix might possibly, therefore, be brought about by the vital activity of these cells. Moreover, the formed matrix is always in vital relation with undifferentiated connective tissue, which may at any time undergo specialization for the purpose of construction or destruction. There is therefore no basis for comparison between pathologic conditions of bone and enamel.

The Form of the Structural Elements.—The enamel is made up of prismatic rods of inorganic matter, held together by an inorganic cementing substance. All other calcified tissues are made up of fibrous intercellular substance, containing inorganic salts and usually arranged in layers.

The structure of the enamel differs so greatly from all other calcified tissues that it is difficult to compare them briefly.

PLATE III

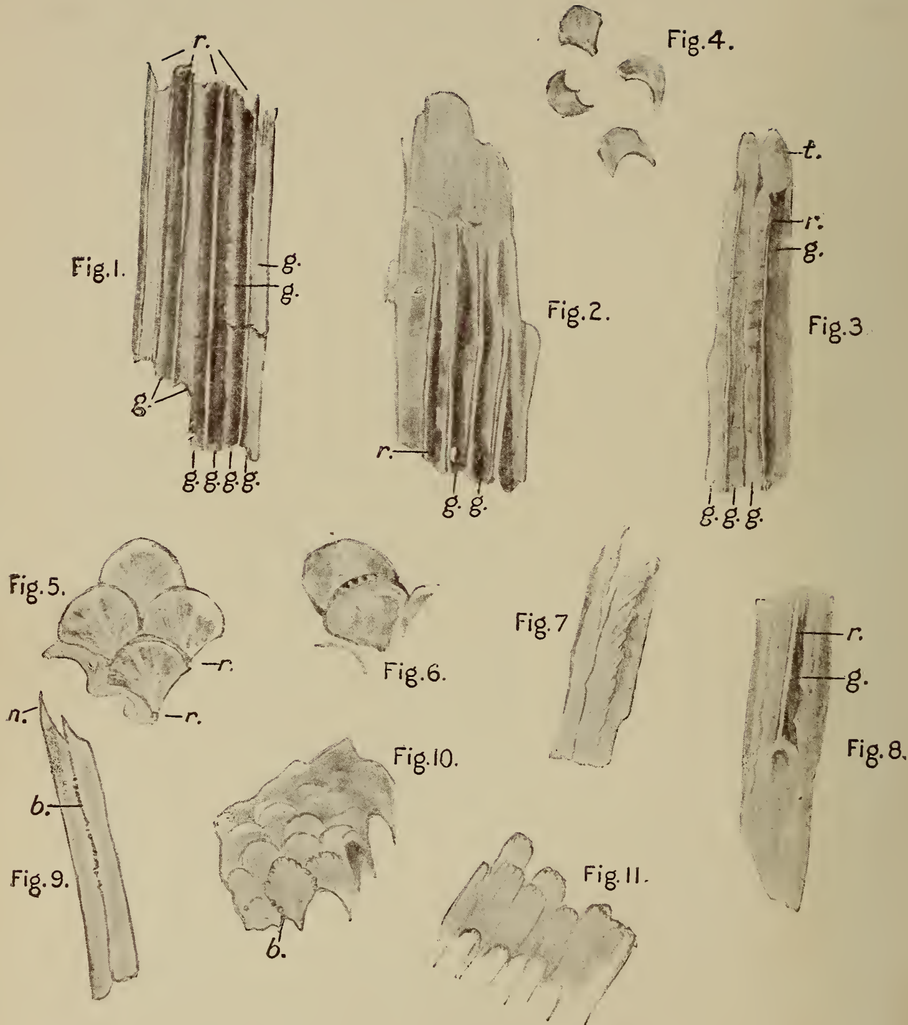


Fig. 1.
r.
g.
g.
g.
g. g. g. g.
Fig. 2.
r.
g. g.
Fig. 3
t.
r.
g.
g. g. g.
Fig. 4.
Fig. 5.
r.
r.
Fig. 6.
Fig. 7
Fig. 8.
r.
g.
Fig. 9.
n.
b.
Fig. 10.
b.
Fig. 11.

CHAPTER IV.

THE STRUCTURAL ELEMENTS OF THE ENAMEL.

THE enamel is composed of two structural elements:

1. The enamel rods or prisms, sometimes called enamel fibers.
2. The interprismatic, or cementing substance.

Enamel Rods.—The enamel rods are long, slender, prismatic rods irregularly five or six-sided[1] and alternately expanded and constricted throughout their length (Plate III and Fig. 9). They are from three and four-tenths to four and five-tenths microns in diameter, and many of them extend from the dento-enamel junction to the surface of the enamel. They are of the *same diameter at their outer and inner ends.* This last statement is emphasized, as the direct opposite is stated in some standard text-books of histology. In the formation of the tissue they are arranged so that the expansions in adjoining rods come opposite to each other, and do not

[1] This statement of the shape of the enamel prisms must be taken as a general statement, just as columnar epithelial cells are described as five-sided in cross-section. In the enamel prism, as in the epithelial cell, the form is the result of mutual pressure, the outlines are never regular, and unevenness in the distribution of the pressure, or lack of balance in direction will modify the form of the prisms. For further study of the form and relation of the enamel rods the student is referred to The Microscopic Anatomy of the Teeth, by J. Howard Mummery, Chapter II.

DESCRIPTION OF PLATE III.

Drawings from teased preparations of enamel from elephant, except Figs. 5, 6, 7 and 8, which are from sections.

FIG. 1.—Double-grooved prisms (elephant). *r*, ridges; *g*, grooves. The ridges are often seen projecting beyond the extremities of fragments.

FIG. 2.—Single-grooved prisms (elephant). *r*, ridge; *g*, grooves.

FIG. 3.—Two double-grooved prisms, transverse above (elephant).

FIG. 4.—Fragments of prisms in transverse fracture (elephant).

FIG. 5.—Four prisms from a section (elephant), showing surface marking and prominence of the ridge at *r*.

FIG. 6.—From elephant: bridges in transverse section. The interprismatic substance appeared dark and the bridges are very conspicuous as white lines.

FIG. 7.—Elephant. From a section, showing a wing process in the enamel.

FIG. 8.—Elephant. From a section, showing ridges and grooves. *r*, ridges; *g*, grooves.

FIG. 9.—Two prisms from elephant, showing needle-splitting (*n*) and intercolumnar bridges (*b*).

FIG. 10.—Fragment of elephant enamel in transverse section. Two entire double. concave prisms are seen projecting, with feather edges and intercolumnar bridges (*b*).

FIG. 11.—Fragments of prisms seen obliquely (elephant).

interlock with the constrictions, so that there is alternately a greater and a less amount of cementing substance between them.

It is evident that the outer surface of the enamel is much greater than the surface of the dentin at the dento-enamel junction. This greater area is obtained in two ways:

1. The rods are at right angles to the dentin at the dento-enamel junction, but are seldom at right angles to the outer surface. This may be illustrated by bending the leaves of a book, or cutting a stack of paper obliquely. The sheets of paper are of the same thickness, but when cut at right angles to the sheets the area of the cut surface is not so great as when the leaves are cut diagonally.

Fig. 9.—Enamel rods isolated by scraping. (About 800 ×)

2. Many of the enamel rods undoubtedly extend from the dento-enamel junction to the surface of the enamel, though it is difficult to follow individual rods through this distance, but there are also short rods which extend from the surface part way to the dentin. These short rods end in tapering points between converging rods that extend the entire distance. The short rods are specially numerous in the most convex portion of the surface, as over the tips of the cusps, occlusal edges, and marginal ridges. These areas therefore become of special importance in connection with the formation of enamel walls, as will be considered in detail later on (Fig. 105).

Differences between Enamel Rods and Cementing Substance.—While the cementing substance and the substance of the rods are both entirely inorganic, or, more correctly, are composed entirely of inorganic salts, they differ in physical and chemical properties as follows:

1. The cementing substance is not as strong as the prismatic substance.
2. The cementing substance is more readily soluble in dilute acids than the rod substance.

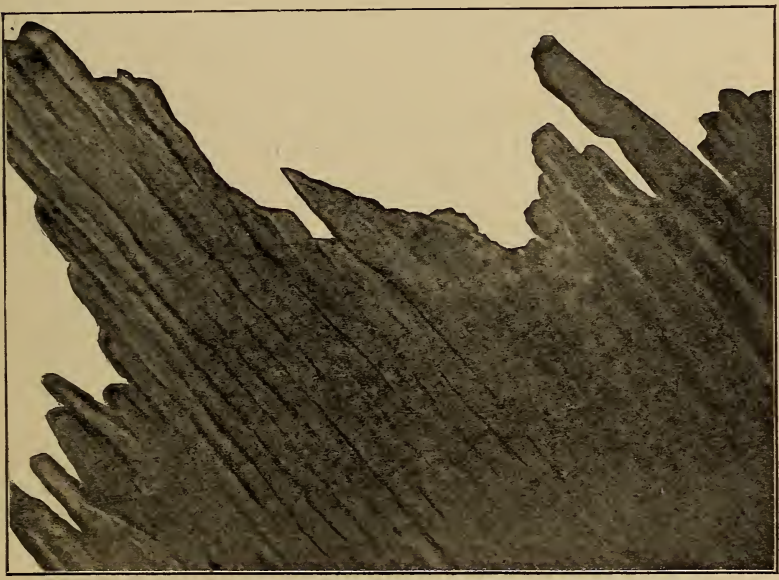


Fig. 10.—Enamel rods in thin etched section. (About 800 ×)

3. The cementing substance is of slightly different (greater) refracting index than the substance of the rod. The author wishes to emphasize these statements, as the exact opposite is found in some of the standard texts, at least concerning the first and second statements. The facts are, however, so easily demonstrable that anyone may satisfy himself without difficulty.

Relative Strength of the Enamel Rods and the Cementing Substance.—The cementing substance is not as strong as the substance of the rods. The most striking characteristics of the enamel, and the first to attract the attention of the student and the operator, are its hardness and its tendency to split or cleave in certain directions.

On examination it is found that this is determined by the direction of the rods, and is caused by the difference in strength between the two substances. Sections ground at right angles to the rod direction are very difficult to prepare because of the tendency of the section to break to pieces.

If a section that is beginning to crack (Fig. 11) is studied, the crack is found to follow the line of the cementing substance running around the rods. In some places a rod may be split through its center, but most of the rods remain perfect, and the cementing substance breaks. In the same way a section cut in the direction of the rods shows the crack following the lines of the cementing substance (Fig. 12), here and there breaking across a few rods, and then following the direction again; but the rods separate on the line of union, not at the centers of the rods. This fact becomes fundamental in the cutting of enamel and in the preparation of strong enamel walls.

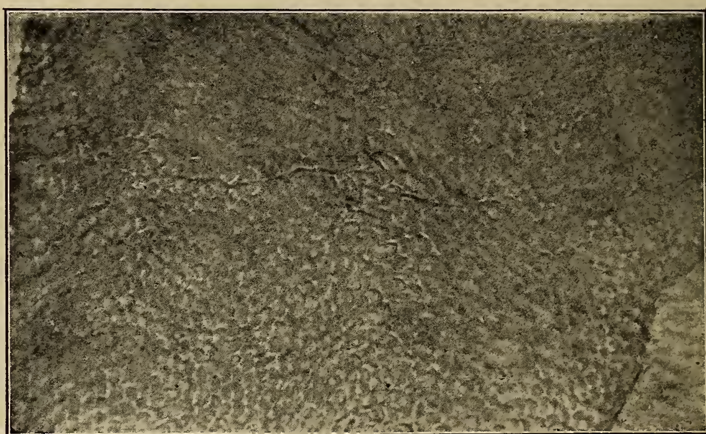


Fig. 11.—Transverse section of enamel rods. (About 80 ×)

Relative Solubility of Enamel Rods and Cementing Substance.—If a thin section of enamel cut parallel with the direction of the enamel rods is mounted in water and hydrochloric acid (2 per cent.) is allowed to run under the cover-glass and the action observed, it will be seen to attack the cementing substance more rapidly, dissolving it out from between the enamel rods and attacking their sides. If the action is stopped the ends of the rods will be seen projecting like the pickets of a fence, as shown in the photograph

(Fig. 13). The more dilute the acid the greater will be the distance to which the cementing substance is removed before the rods are destroyed.

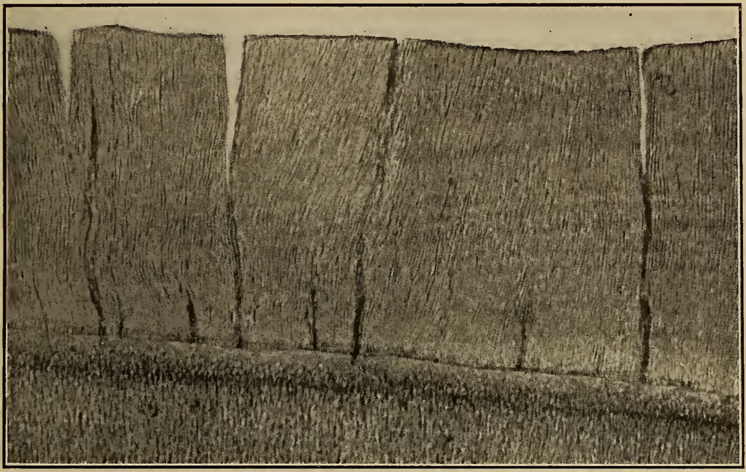


FIG. 12.—Enamel showing direction of cleavage. (About 70 ×)

Etching.—If a section of enamel is ground at right angles to the direction of the rods, mounted in glycerin and photographed, the outline of the rods will be seen with difficulty (Fig. 14). The refracting index of the two substances is so nearly the same that the section seems of almost uniform transparency. The thinner the section,

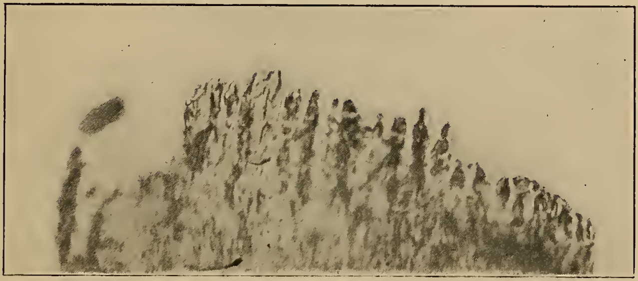


FIG. 13.—The effect of acid on a section of enamel.

the greater will be the difficulty of recognizing the rods. Oblique illumination and the use of a small diaphragm will, however, resolve them. If the section is washed and treated with 2 per cent. hydrochloric acid for a few seconds, washed, and remounted in glycerin, the rods are distinctly outlined (Fig. 15). The acid attacks the cementing substance and the surface of the section is etched as if an engraving tool had been run around the rods. The fine grooves on the surface refract the light and outline the rods. The difference in appearance in longitudinal sections, that is, sections parallel with the direction of enamel rods, is quite as striking. For the study

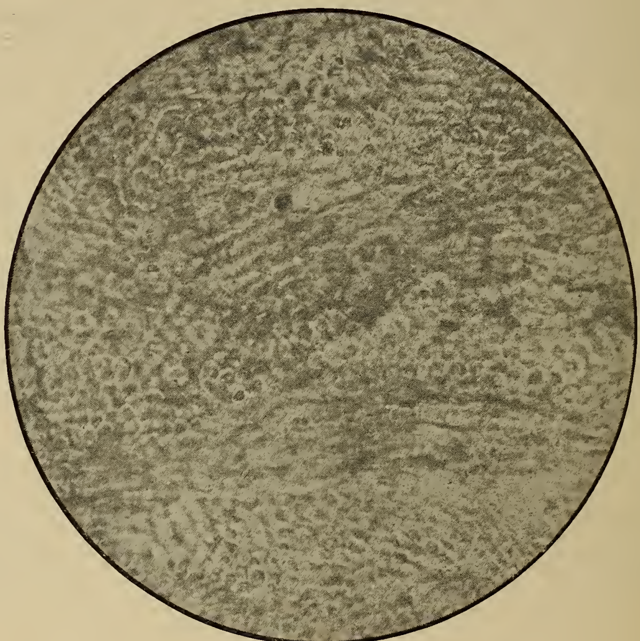


Fig. 14.—Enamel ground at right angles to the rods. Not treated with acid. (About 500 ×)

of enamel rod directions this etching is of the greatest importance. Only one side of the section should be acted upon by the acid, and the section should be mounted etched side up. If etched upon both surfaces, the grooves in the lower surface cannot be in focus at the same time as those of the upper surface and will blur the definition.

The difference in the solubility of the rods and cementing substance is beautifully illustrated in the effect of caries on the structure of the enamel and caries of the enamel cannot be understood unless these fundamental facts are remembered. The question, "What causes the difference in solubility between the enamel rods and the cementing substance?" cannot be satisfactorily answered at the present time. While both the rods and the cementing substance are normally composed entirely of inorganic salts, there may be different salts in the two substances, or the salts may be in different physical condition. There is great need for careful work in this field. Recent work has strongly emphasized the distinctness of the two structural elements of the enamel.

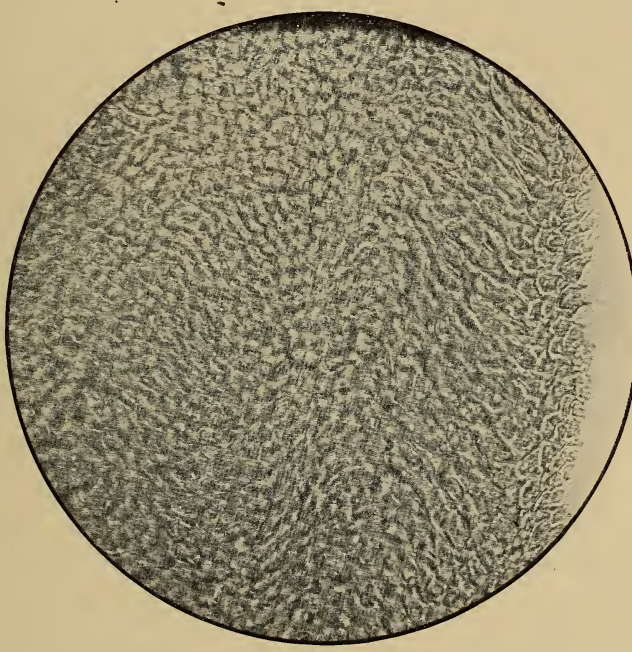


FIG. 15.—The same section as Fig. 14 after treatment with acid. (About 500 ×)

First, the study of the beginnings of caries of the enamel, and the effect of caries upon the structure of the enamel, brought out the difference in solubility in acids and showed the extent of tissue injury before a cavity is formed. Later, the study of hypoplasia developed the fact that certain pathologic or abnormal conditions may hinder or entirely prevent the formation of the rods while the cementing substance is formed, and still more recently the investigation of dystrophies of the enamel occurring in certain prescribed localities, showed perfect rod formation and entire absence of the cementing substance. These facts suggest the hypothesis that the enamel rods and the cementing substance have a different origin, or are formed by different cells, and that pathological conditions may prevent the formation of one and not the other. In view of these factors it is very necessary that a new investigation of the process of enamel formation be undertaken, as present knowledge of the process does not explain such conditions.

Difference in Refracting Index between the Rods and the Cementing Substance.—The cementing substance is of slightly greater refracting index than the substance of the rods. If it were not for this it would be impossible to see the rods in unetched sections, either longitudinal or transverse. The appearance of striation seen in longitudinal sections is also dependent upon this difference in action on transmitted light.

THE EFFECT OF CARIES ON THE STRUCTURE OF THE ENAMEL.

At this point the effect of caries on the structure of the enamel should be studied as a demonstration of the difference in solubility between the enamel rods and the interprismatic substance.

During the last ten years of his life the work of the late Dr. G. V. Black was largely devoted to the study of the beginning o caries of the enamel and the extent of tissue injury before an actual cavity is produced. This has placed a tremendous emphasis upon the value for the preservation of the teeth, of the treatment of caries in its early rather than in its later stages. It is safe to say that if caries progresses until a patient is aware of a cavity, the tooth has been injured more than is necessary in the most radical treatment of the same cavity in its beginning stages. One who has not studied carefully the effect of caries on the structure of the enamel, so as to recognize the extent of injury to the structure of the tissue by its appearance to the naked eye, can never be considered fit to prepare cavities as a treatment for the disease. The beginnings of caries must be divided into two classes: (1) Those occurring in natural defects of structure; (2) those beginning upon smooth surfaces.

Caries Beginning in Natural Defects of Structure.—These are the positions in which caries first appears and in which it presents the greatest intensity, because they offer ideal conditions. Such open grooves and imperfectly closed pits in the enamel as are illustrated in Chapter IX become filled with food debris, which furnish ideal culture media for acid-forming bacteria. At the opening of the defect the acid is washed away by the saliva as fast as it is formed, but at the bottom of the groove it is confined and acts upon the enamel, dissolving out the cementing substance from between the rods and following the rod direction toward the dento-enamel junction. The form of the disintegrated tissue in such positions is always that of a cone or wedge, with the apex at the opening of the pit or groove and the base toward the dento-enamel junction. The formation of acid in these positions is often so rapid and the confinement so perfect that the carious process here manifests its greatest intensity, the action often dissolving the rods as well as the cementing substance and progressing across the rods. But even when the action follows the rod direction, the form will be broader toward the dentin, as the rods are inclined

FIG. 16.—A split tooth, showing caries beginning in an occlusal groove.

toward the defect. Figs. 16 and 17 show split teeth illustrating the disintegration of the enamel around occlusal defects. The disintegration area appears white by reflected light because the cementing substance has been removed from between the rods and the resulting air spaces refract the light. As soon as this disintegration reaches the dento-enamel junction, the acid formed passes through the now porous enamel and acts much more rapidly upon the dentin. Because of the branching of the dentinal tubules at the dento-enamel junction, the action upon the dentin spreads rapidly along this line. Soon some of the loosened rods between the bottom of the defect and the dentin are either entirely dissolved or displaced or dislodged, and the microörganisms are admitted to the dentin. The decalcified dentin matrix becomes food material for the bacteria, and the space produced by the destruction of tissue furnishes greater space for decomposing foodstuffs. The acids formed attack the enamel from within outward, producing

Fig. 17.—A split tooth, showing caries progressing in an occlusal groove.

what has been called backward or secondary decay of enamel. At the mouth of the defect the acid is still washed away, and there is little action upon the tissue. The condition progresses, therefore, until, as in Fig. 18, the entire occlusal enamel has been undermined, and all of the undermined area has been greatly weakened

Fig. 18.—A split tooth, showing the undermining of the occlusal enamel by caries spreading at the dento-enamel junction.

by the solution of the cementing substance from between the rods. In ground sections of such areas as shown in Fig. 21 the disintegrated area appears dark by transmitted light. Fig. 19 shows the progress of secondary decay from an occlusal cavity. In this way it often happens that the entire occlusal enamel is destroyed before the original defect is noticeably enlarged.

The general form of the disintegrated area in caries beginning in natural defects may be described diagrammatically, as in the enamel a cone or wedge with the apex toward the mouth of the defect and the base toward the dento-enamel junction, and in the

Fig. 19.—A section showing the undermining of the enamel and secondary or backward decay at *1*.

dentin a cone or wedge with the base at the dento-enamel junction and the apex toward the pulp.

Caries Beginning on Smooth Surfaces.—Caries upon smooth surfaces of the enamel is always due to the growth of a colony of bacteria which becomes attached to the surface by the formation of material, causing them to adhere to the surface and at the same time confining their acid products in contact with the enamel preventing its dissipation in the saliva and allowing it to combine with the inorganic salts of the tissue elements. This is not the place to consider the bacteriology of caries, but the effect upon the structure of the enamel cannot be understood without a clear conception of the microbic plaques. A growth of masses of micro-organisms upon the surface of a tooth does not constitute a plaque. Many very filthy mouths are found where most of the surfaces of the teeth are covered by thick, furry masses, and where there is little or no attack of the enamel. Either acid is not formed or it is at once lost by solution in the saliva. Caries shows the greatest intensity in comparatively clean mouths, in which something in the nature of the saliva causes the bacteria to produce a tough zoöglea, which attaches them to the tooth surface and confines the products of their activity. This zoöglea presents some of the phenomena of a dialyzing membrane. Through it the micro-organisms receive their food materials, and their products are neutralized by chemical action on the surface upon which the colony is growing. Colonies lodge in the most favorable spots and extend from these points into areas that are less liable to maintain their attachment. The more perfect the confinement of the acid, and the more rapid the rate of its formation, the greater will be the intensity of the destructive process. The more easily the colony is able to maintain itself in its position and extend upon the surface, the greater is the liability. As the colony becomes thickest at the point of beginning, it is evident that the most acid is formed here, and it is therefore the point of greatest intensity. It is also the point at which the growth began, and therefore the spot where the action on the tissue has been longest in operation. It is also apparent that there may be great intensity with limited liability, and great liability with very low intensity, and the effect upon the tissue will be different in the two cases.

The appearance of the tissue becomes an index for estimating the intensity and liability in a given case. The character of the effect of the disease on the appearance of the enamel, as well as the direction of the extension upon the surface of the tooth, become most important factors in the diagnosis of any case, and the diagnosis is the basis for the treatment required. The increased appreciation of the extent of disintegration of the enamel before an actual cavity is apparent in a tooth has been one of the most important results of Dr. Black's study of caries of the enamel. The author has been intimately associated with this work, and has been amazed at the extent and character of the effect of caries upon the structure of the enamel in what may be called the early stages of the disease.

Progress of Caries.—A colony of bacteria becomes attached to the proximal surface of an incisor just to the gingival of the contract point, and remains there some time. If the surface of the tooth can then be examined, a white spot will be seen at Fig. 21; the area appears white because the cementing substance has been removed from between the enamel rods, as will be seen later, and the air that occupies the spaces diffuses the light. If a tooth is split through such a spot and viewed from the surface, the appearance will be as shown in Fig. 20. If a section were ground through the spot and the tissue preserved, the ends of the enamel rods

Fig. 20 Fig. 21

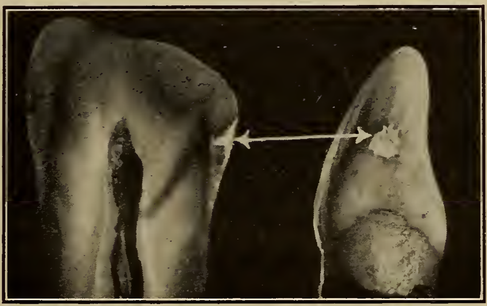


Fig. 20.—A split tooth cut through such a white spot as is shown in Fig. 21.

Fig. 21.—A superior central incisor, showing a white spot just to the gingival of the contact point.

would be seen pointed and projecting like the pickets of a fence, giving the same appearance as that produced by the action of acid upon a ground section, as illustrated in Fig. 15.

The surface of the enamel is therefore no longer smooth, but roughened. The roughness may often be felt by passing a very fine-pointed steel explorer over the surface. If the colony be dislodged at this stage it is evident that it is much easier for a new one to become attached. These whitened areas are often invisible unless the tissue is dried, because the saliva fills the spaces. If the surface is dried the refraction of the light by the air whitens the affected area.

A good comparison is furnished in a very familiar phenomenon. Snow is white because the air and the microscopic ice crystals are of different refracting index, and the light is diffused by passing from air and ice crystals. If a snowball is saturated with water it loses its whiteness and becomes translucent, because the water, which is nearly of the same refracting index as ice, fills the spaces between the ice crystals, and the light is not diffused. If the white area of such a tooth is split through the center with an aluminum disk charged with emery powder, the enamel rods will be found

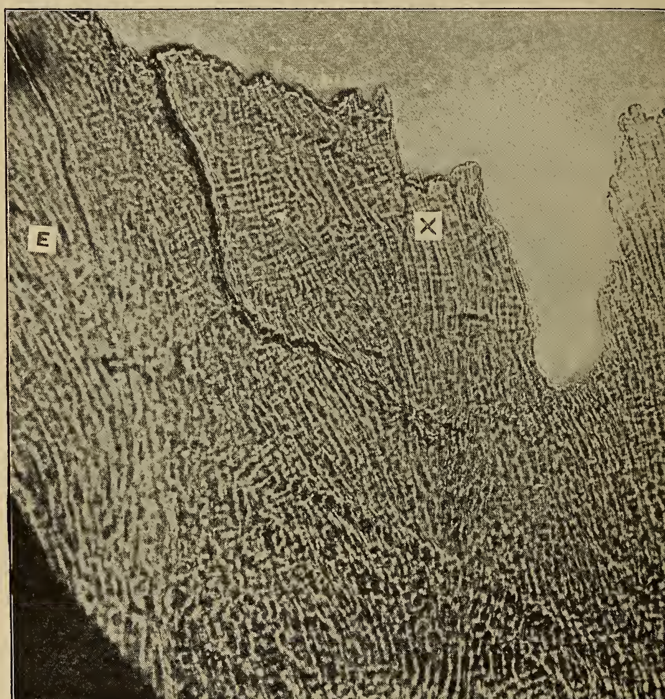


Fig. 22.—A thin section of carious enamel ground on the cover-glass with balsam: *E*, sound enamel; *X*, carious enamel in which the cementing substance had been dissolved from between the rods.

entirely separated by the solution of the cementing substance, and the cross-striation will be much more apparent because the unevenness in the diameter of the rods has been increased by the action of the acid.

Formerly it was impossible to grind a section through such a spot and preserve the tissue. Until methods were devised by Dr. Black, it was impossible to preserve the tissue and examine its condition. These methods demonstrate definitely that in the disintegrated area the cementing substance is dissolved in large areas before any of the rods are dissolved or destroyed. The first sections

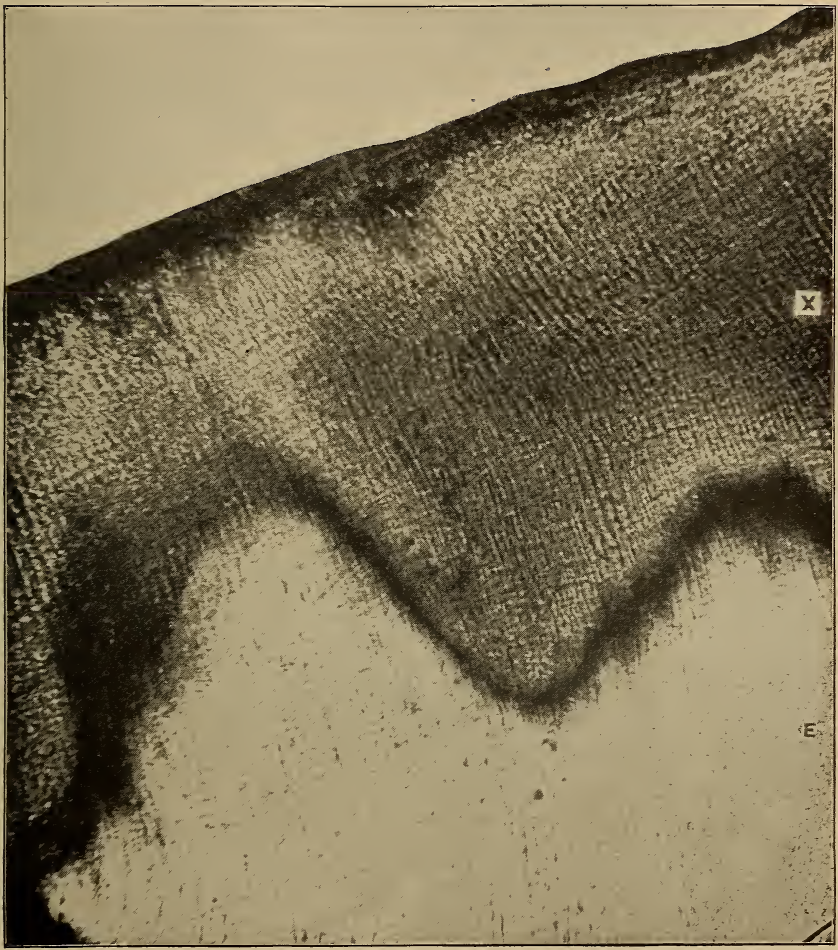


Fig. 23.—Carious enamel ground on the cover-glass by the shellac method. In the region *X* the cementing substance dissolved from between the rods has been replaced by shellac.

of such areas were obtained by polishing the surfaces and cementing the split tooth to the cover-glass with balsam, completing the grinding and mounting without loosening the section. In this way the spaces between the rods were filled with balsam and so were held in place. Fig. 22 shows a photograph of a section made in this way, and the spaces between the rods and the distinct cross-striation are seen. Later it was found that by dehydrating and immersing in a solution of brown shellac, the shellac could be made to take the place of the lost cementing substance, then the polished surface of the sawed-out section could be fastened to the cover-glass with shellac, and the specimen handled more easily. Fig. 23 shows a photograph of carious enamel made in this way. The rods are preserved in place and the dark shellac marks the disintegrated area very clearly.

Stages in the Progress of Caries.—The progress of caries on smooth surfaces of the enamel may be divided into three periods, according to its effect upon the structure of the tissue.

1. From the lodgement of the colony until the action reaches the dento-enamel junction.
2. From the reaching of the dento-enamel junction until the rods begin to fall out.
3. After a cavity is produced.

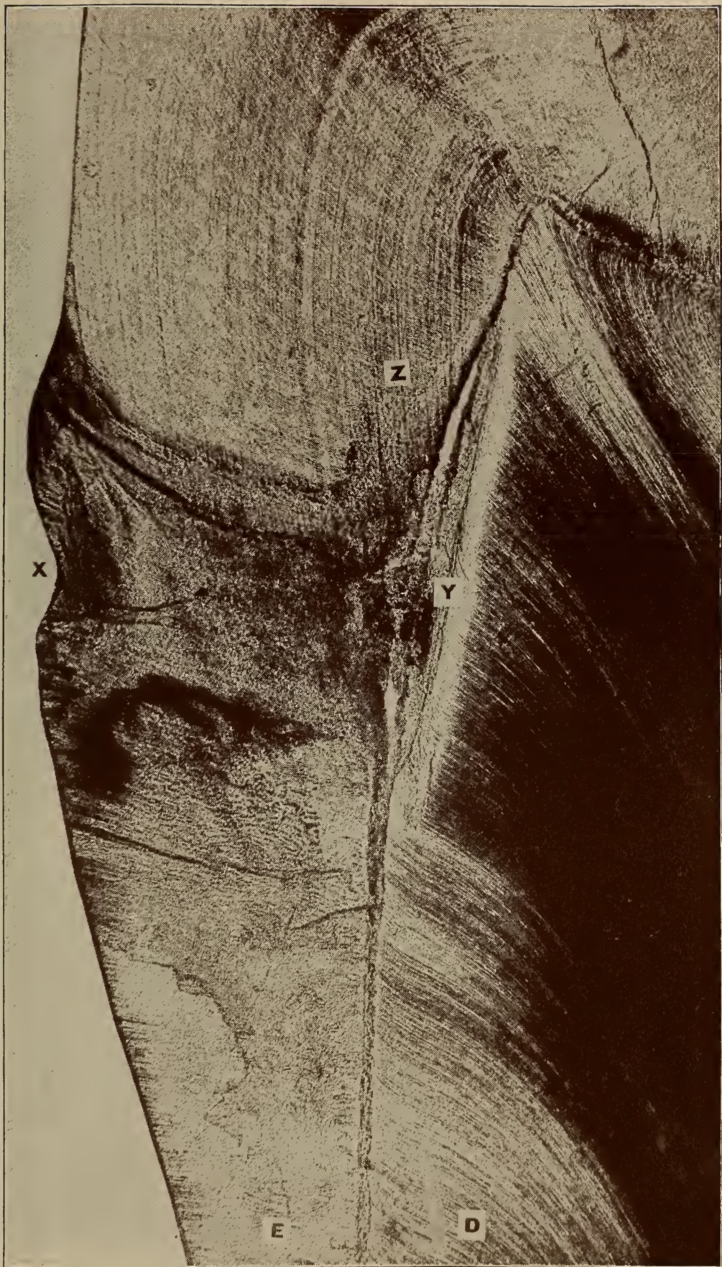
First Period.—The form of the disintegrated tissue in the first period is always that of an irregular cone. Its base is on the surface of the enamel, its outline is the boundary of the colony, and the apex is toward the dentin in the direction of the enamel rods from the starting-point of the colony. The inner boundary of the area is never even, but shows flame-like extensions toward the dentin in the direction of the rods. This is more marked in some cases than in others, and sometimes suggests that the presence of a colony on the surface has been intermittent (Plates IV, V, VI).

The boundary between the perfect and the disintegrated area is usually marked by a darker area, the significance of which is not now understood. If the disease progresses continuously the affected tissue always appears white by reflected light, but if the progress has been intermittent, especially if there have been considerable periods in which no colony has been attached to the surface, the area darkens, becoming brownish or almost black. This is produced by organic materials filling the space between the enamel rods and decomposing, with the probable formation of sulphides of dark color in the spaces. If immunity to caries is attained before the effect upon the tissue has penetrated to the dento-enamel junction, this will occur, and the spot changes from a white to a brownish or black color. Such spots will be found in some places

PLATE IV

A Section through a Carious Spot in the First Period.
Showing extension of the attack on the surface toward the gingival.

PLATE V



A Section through a Carious Spot in the Second Period.

X, disintegrated area, showing swelling of the surface; *Y*, space between enamel and decalcified dentin; *Z*, secondary caries of the enamel; *E*, sound enamel; *D*, dentin.

PLATE VI

A Section through a Carious Spot in the Second Period.

X, disintegrated enamel at the point of first lodgement of the colony; *Z*, disintegrated enamel as the result of the extension of the colony on the surface toward the occlusal; *E*, sound enamel; *D*, dentin.

on most teeth extracted from immune persons. Work of Dr. Miller has indicated that such spots are more resistant to the progress

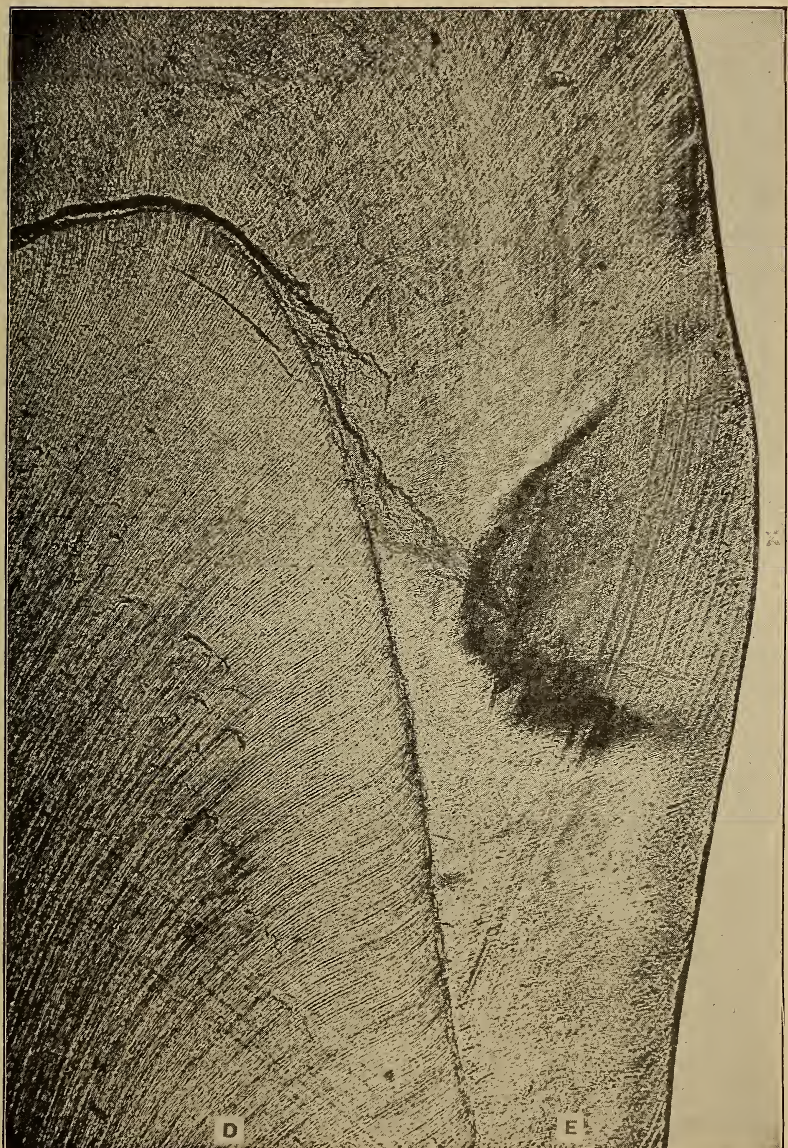


Fig. 24.—A section through a white spot in the first period of attack: *X*, disintegrated enamel; *E*, sound enamel; *D*, dentin.

of caries than perfect enamel surfaces. At any time during the first period, therefore, the destruction may be arrested by the coming of immunity, which prevents the attachment of colonies to the tooth surface by the formation of plaques.

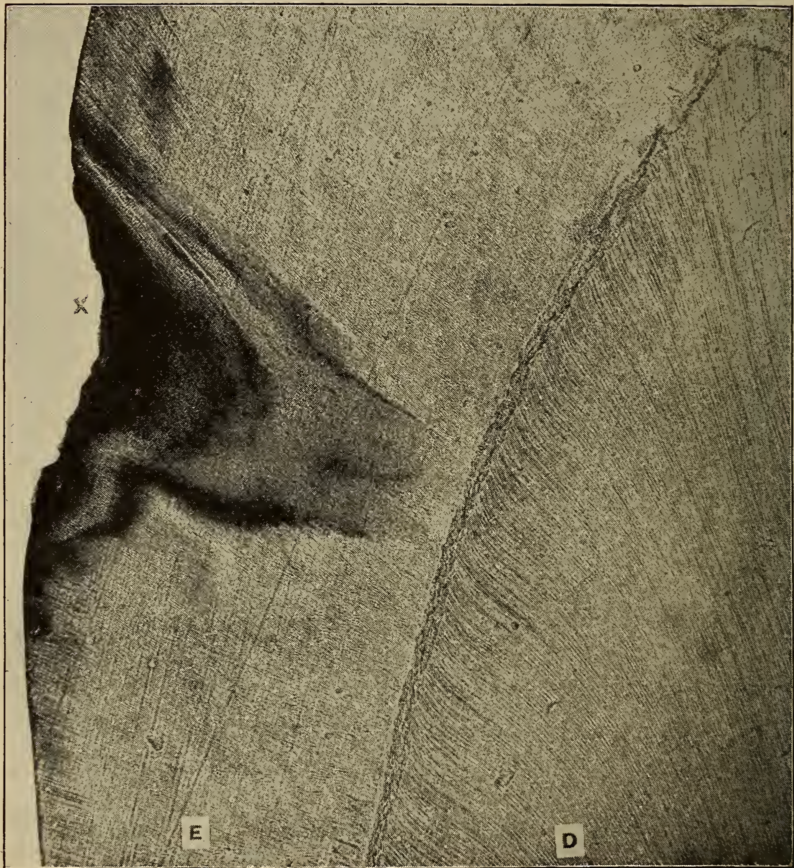


Fig. 25.—A section through a carious spot in the first period. The attack has apparently been slow and intermittent: *X*, disintegrated enamel; *E*, sound enamel; *D*, dentin.

Second Period.—This period extends from the time when the action of the acid reaches the dento-enamel junction until the rods are destroyed or fall out. As soon as the solution of the cementing substance reaches the dento-enamel junction at the point of the advancing cone, the solution of the inorganic salts from the dentin matrix begins. It must be remembered that the acid is formed by the microörganisms on the surface of the

Fig. 26.—A section through a carious spot in the first period, showing the flame-like projections toward the dentin: *X*, disintegrated enamel; *E*, sound enamel; *D*, dentin.

enamel, and filters through the spaces between the enamel rods. The decalcification of the dentin may be considerable, while the surface of the enamel is still preserved. In this period the swelling of the surface is always noticeable. This results in increasing the area of the contact and therefore allowing the colony to extend its limits, increasing the extent of the surface attack. This is especially noticeable toward the gingival, and is shown in Plate IV, which is, however, shown in the first period of caries. In the disintegrated area in this stage, as well as in the first stage, the diameter of the enamel rods is always considerably reduced and the striation rendered more apparent. In caries of great intensity

Fig. 27. — A tooth split through a spot, showing great intensity but low liability.

Fig. 28.—A tooth split through spots, showing low intensity but great liability.

but low liability the reduction in the diameter of the enamel rods is rapid, and they are soon destroyed, while the area of the surface attacked is small (Fig. 27).

In caries of low intensity but great liability the diameter of the rods is slowly reduced, while the area of surface attacked, and consequently the area of disintegration, is large (Fig. 28). These conditions should be studied in the macroscopic appearance of caries at the chair.

The decalcified dentin matrix shrinks and more or less of a space is formed under the enamel.

The action of the acid follows the tubules of the dentin toward the pulp, and spreads through their branches laterally near the dento-enamel junction so that the form of the disintegrated dentin is always that of a cone, with the base at the dento-enamel junction and the apex toward the pulp chamber. It is important, however, to remember that in this stage no microörganisms have entered the tissue, and the effect upon it is the result of the action of substances formed upon the surface. The extent of enamel disintegration and decalcification of dentin, in this stage, is much greater than anyone supposed before such specimens as the present illustrations were made.

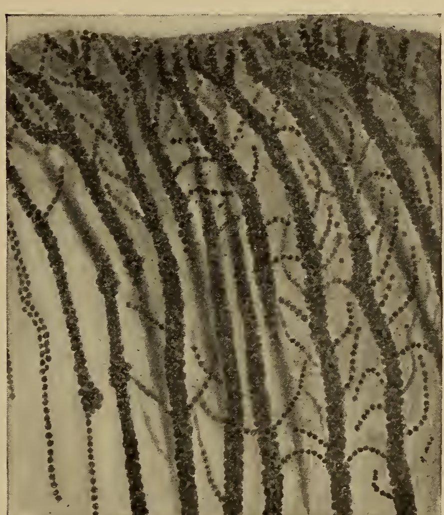


Fig. 29.—A drawing showing the microörganisms of caries growing through the dentinal tubules. (G. V. Black.)

Third Period.—This embraces the period after the enamel rods have begun to fall out and an actual cavity is apparent. As soon as this occurs the surface of the tooth at the point where the formation of the colony began is destroyed and the protected point is lost, and the extension of surface attack ceases. The microörganisms are admitted to the dentin, where they grow through the dentinal tubules, spreading rapidly at the dento-enamel junction (Fig. 29). The dentin is always decalcified in advance of the penetration of the microörganisms. The acid formed within the cavity attacks the cementing substance between the enamel rods, and proceeds from the dento-enamel junction outward. This is called secondary or backward decay of the enamel, and as a result of it, large areas are disintegrated until they are sufficiently weakened to break into the cavity. This condition is shown in Fig. 19, in which the area indicated by *1* has had the cementing substance entirely removed from between the rods, and is in the same structural condition as the disintegrated areas in the first and second stage. It is safe to say that in the past few cavities have been filled until the enamel has caved in. It is equally certain that in a large proportion of cases, by the time this has happened, the removal of all disintegrated tissue will require a greater loss of tooth substance than would be required for the prevention of a new surface attack, at the margin of the filling, if the case had been treated as a beginning instead of a burrowing decay.

CHAPTER V.

CHARACTERISTICS OF THE ENAMEL TISSUE.

From what has been said of the structural elements of the tissue, their physical and chemical properties, and their arrangement in the tissue, it is apparent that the striking characteristics of the enamel are the result of these factors; and that it can be intelligently dealt with only by thinking of it always in these terms.

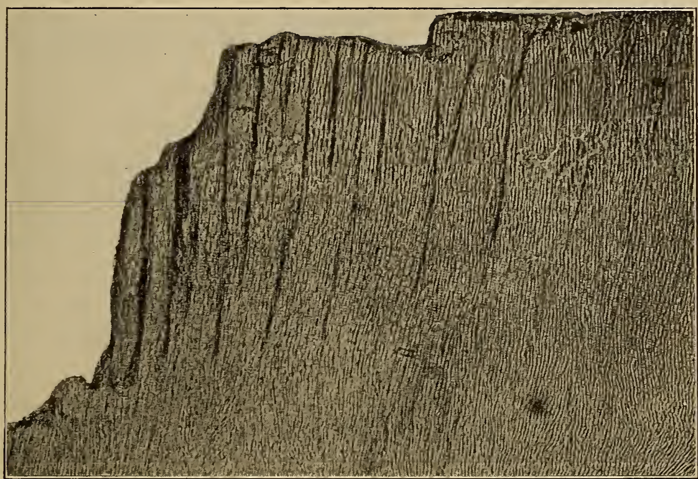


Fig. 30.—Enamel showing cleavage.

The enamel may be crudely compared to a pavement made up of tall columns closely cemented together by an inorganic cement. The wear comes on the ends of the columns, and they furnish great resistance to the abrasion of friction. When supported upon a good and elastic foundation it is very difficult to break it down, but when an opening has been made in it, and the foundation removed from underneath, the columns are comparatively easily split off and tumbled into the opening (Fig. 30). This figure is crude, but it is a very helpful one in learning to think of the enamel in terms of its structural elements.

Straight Enamel.—Upon the axial surfaces of the teeth the rods are usually straight and parallel with each other, and most of split extend from the dentin to the surface. Such enamel will split or cleave in the direction of the rods with comparative ease, and breaks down very readily when the dentin is removed from under it. It will usually cleave through its entire thickness and break away from sound dentin when properly attacked with sharp hand instruments. Such enamel is called straight enamel, as contrasted with gnarled enamel. It is best illustrated by cutting sections labiolingually through the incisors, though there is considerable variation in different teeth (Figs. 12 and 31).

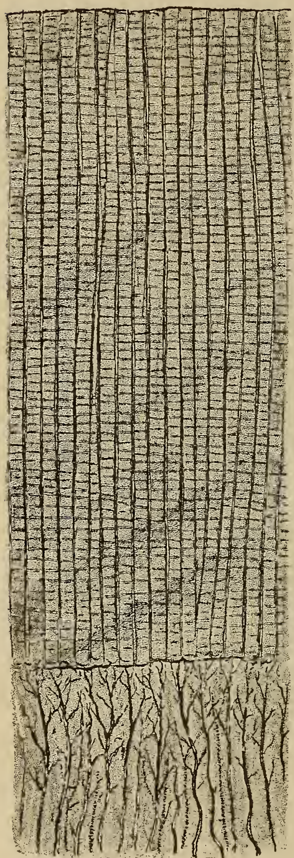


Fig. 31.—Straight enamel rods.

Gnarled Enamel.—Upon the occlusal surfaces of the molars and bicuspids, and especially over the tips of cusps and marginal ridges, the rods are seldom straight and parallel through the thickness of the enamel, but are wound and twisted about each other, especially in the deeper half toward the dento-enamel junction. This is known as gnarled enamel, and its appearance is in marked contrast with straight enamel.

Toward the surface the rods are usually straight and parallel for a longer or shorter distance, but as the dento-enamel junction is approached they become twisted. This is true of most of the occlusal surfaces of molars and bicuspids, but the gnarled condition extends farther toward the surface over the tips of the cusps, or the point at which the rods were first completed in the growth of the crown. As cleavage is caused by the difference in the strength of the rods and cementing substance, it is easy to see that gnarled enamel will not split or cleave easily when resting upon sound dentin. This is often encountered in extending occlusal cavities. The straight portion will split, but where the rods begin to twist they break off, leaving a portion resting on the dentin which will resist the attack of any cutting instrument from the surface (Figs. 32, 33, and 34).

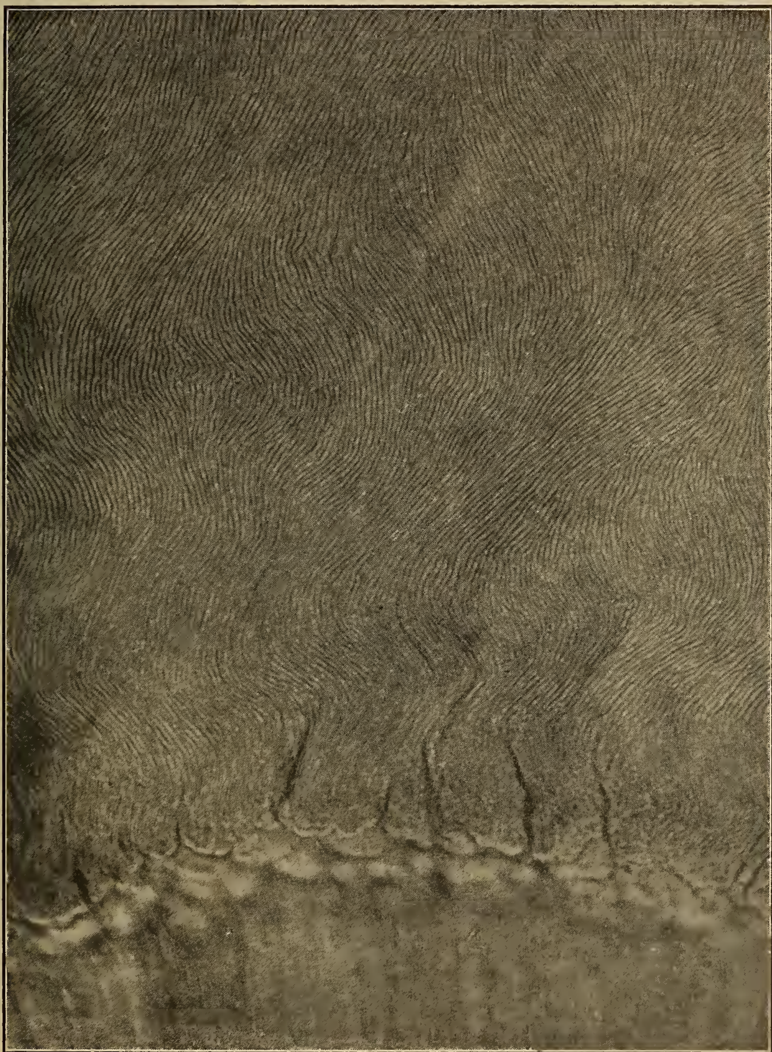


Fig. 32.—Gnarled enamel. (About 80 ×)

The Effect of Structure on the Cutting of Enamel.—The two kinds of enamel may be compared to straight-grained pine wood and a pine knot. The first will split easily in the direction of the fiber, the latter will split only in an irregular way and with the greatest difficulty. This difference in the arrangement of the structural elements leads to the difference in the feeling of various teeth to cutting instruments, and is the basis for the clinical experience of hard and soft teeth. It is not a matter of degree of calcification, but

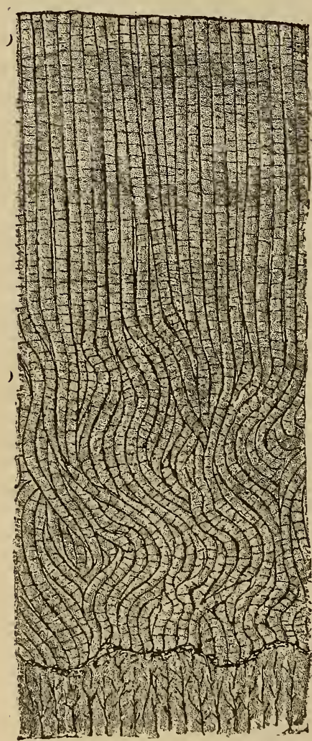


Fig. 33.—Gnarled enamel.

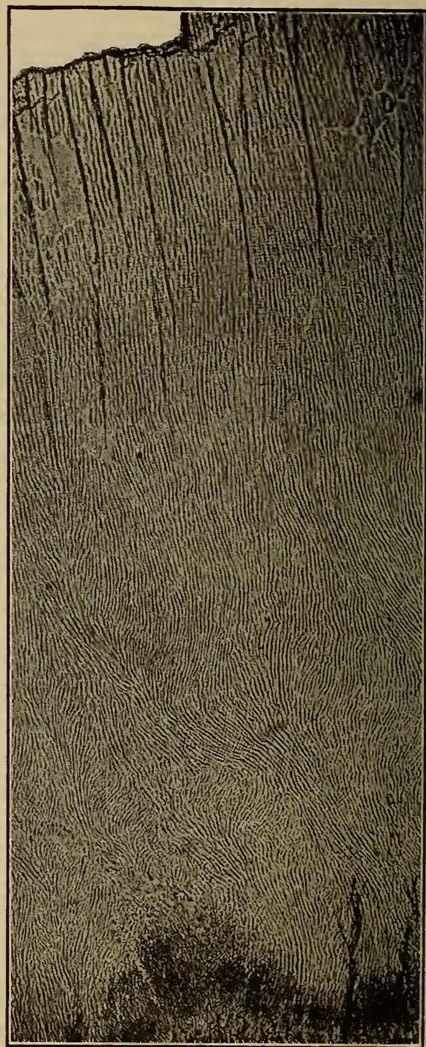


Fig. 34.—Gnarled enamel from etched section. (About 100 ×)

the arrangement of the structural elements, and gnarled enamel will break down as rapidly under the effect of caries as will straight enamel.

From a study of the positions in which the rods are usually twisted about each other, and those in which they are usually straight, it seems probable that the twisting is due to movements in the dental papilla and the enamel organ during the formation of the tissue. These movements may be produced by variations in the blood-pressure which cause oscillations, or shiftings of the tissues on each other. These differences in the arrangement of the structural elements of the enamel must be constantly kept in mind, and will be referred to many times in connection with the use of cutting instruments on the enamel and the preparation of cavity walls.

APPEARANCES CHARACTERISTIC OF ENAMEL.

Striation.—Striation is the appearance of fine light and dark markings occurring alternately in the length of the enamel rods. This is not unlike the striation of voluntary muscle fibers, and has a similar cause. It is seen both in thin sections cut in the direction of the rods, and in isolated enamel rods. It is caused by the alternate expansions and constrictions of the rods and the difference in the refracting index between the rods and the cementing substance.

If isolated rods (Fig. 35) are observed with a $\frac{1}{6}$ or $\frac{1}{12}$ objective, they will be seen to be marked by alternate light and dark areas across the rods; on changing the focus up and down, the light and dark areas will change places, just as in looking at a red blood corpuscle the center may appear dark and the rim light, or the center light and the rim dark, depending upon the exactness of focus. This is caused by the refraction of the light as it passes through the convex and concave portions of the rod. If the cementing substance were of exactly the same refracting index as the rods, when the rods were fastened together in the tissue there would be no appearance of striation, but as it is not, refraction of light occurs in passing from rod substance to cementing substance, and the striation is apparent in sections. There is considerable difference in the distinctness of striation in different sections of enamel. This is probably due to the fact that the cementing substance has more nearly the same refracting index as the rods in some specimens. When the formation of enamel has been studied it will be found that the enamel rods have been formed by globules which are deposited one on top of the other to form the rods, and the cementing substance fills up the space. The globules in the adjacent rods come opposite each other, so that there is alternately a greater and a less amount of cementing substance between the rods. Each cross-mark therefore represents a globule deposited in the formation of the rod, and striation may be said to be a record of the growth of the individual rods (Figs. 36 and 37).

Imperfections in the cementing substance render the striation more apparent because they increase the difference in refraction

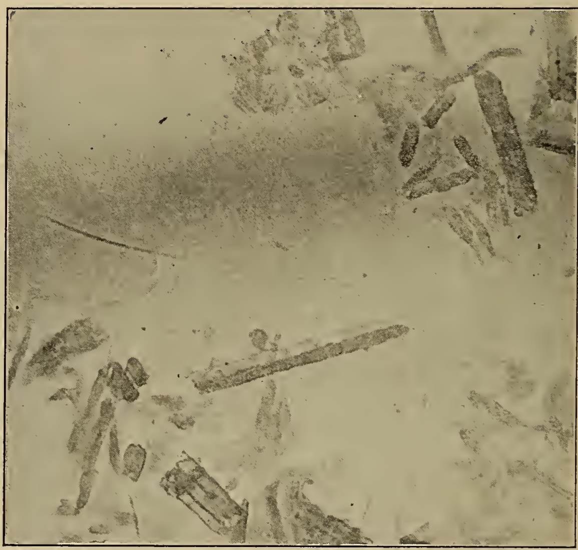


Fig. 35.—Isolated enamel rods. (About 1000 ×)

between the two substances. The action of acid either upon isolated rods or upon sections renders striation more apparent because it attacks the cementing substance faster than the globules forming the rods, and therefore increases the refraction. Von Beber has claimed that the appearance of striation was caused by the action of acid on the section, and that even in mounting in balsam the acidity of the balsam affected the tissue. It is true that any action of acid increases the distinctness of the cross-striation, but it is not the cause of it.

Stratification, or the Bands of Retzius.—If longitudinal sections of moderate thickness are observed with the low power, brownish bands are seen running through the enamel, which suggests the appearance of stratification in rocks. These were first described by Retzius and were named after him—the brown bands or striæ of Retzius. A better name would be incremental lines.

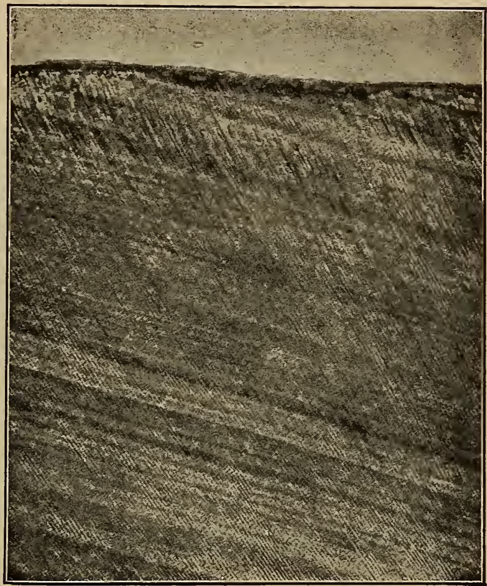


Fig. 36.—Enamel showing both striation and stratification. (About 80 ×)

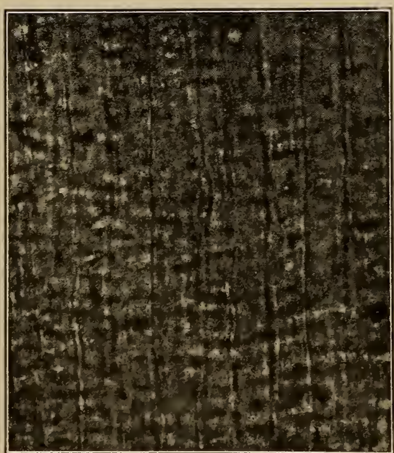


Fig. 37.—Enamel showing striation. (About 1000 ×)

The bands of Retzius, or incremental lines, are caused by actual coloring matter which is deposited with the inorganic salts in the

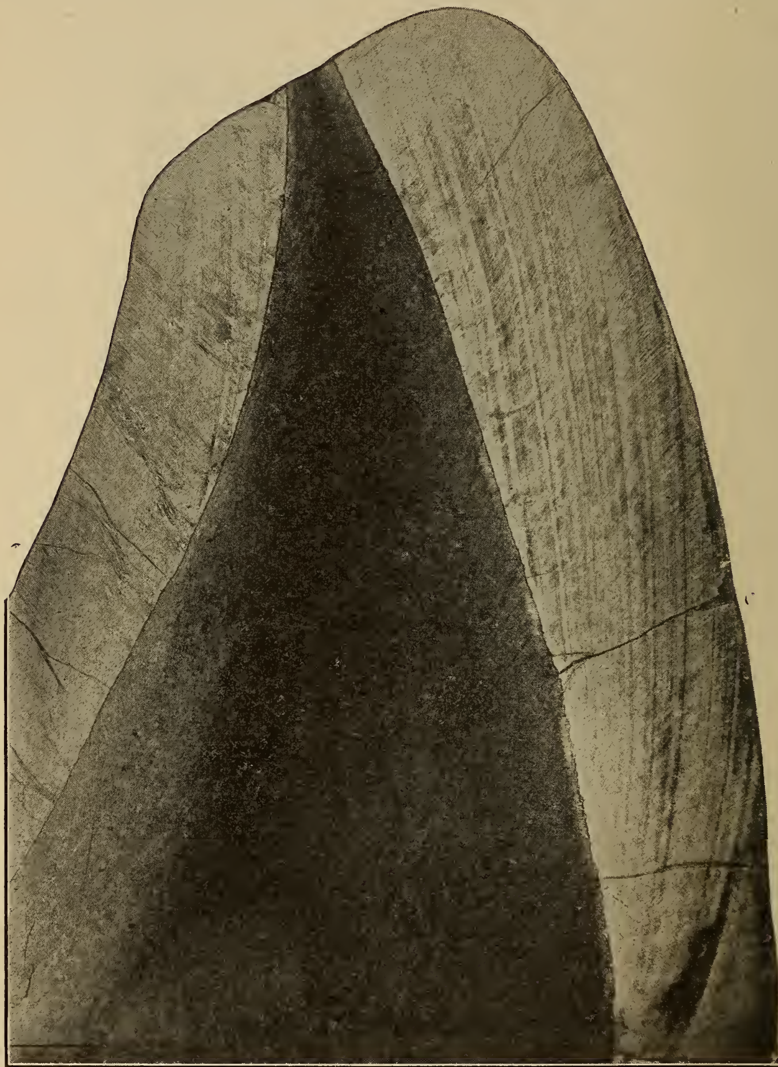


Fig. 38.—Tip of an incisor. (About 50 ×)

formation of the tissue. They are therefore best seen with low powers and in sections that are not too thin. In sections that are thinner than the diameter of a single rod, or less than four microns, they become almost invisible. For the study of the bands of Retzius sections should be ground labiolingually through the incisors, buccolingually through the bicuspids and molars, striking the center of the cusps. They may be studied also in mesiodistal sections, but the sections should be in such a direction as to be at

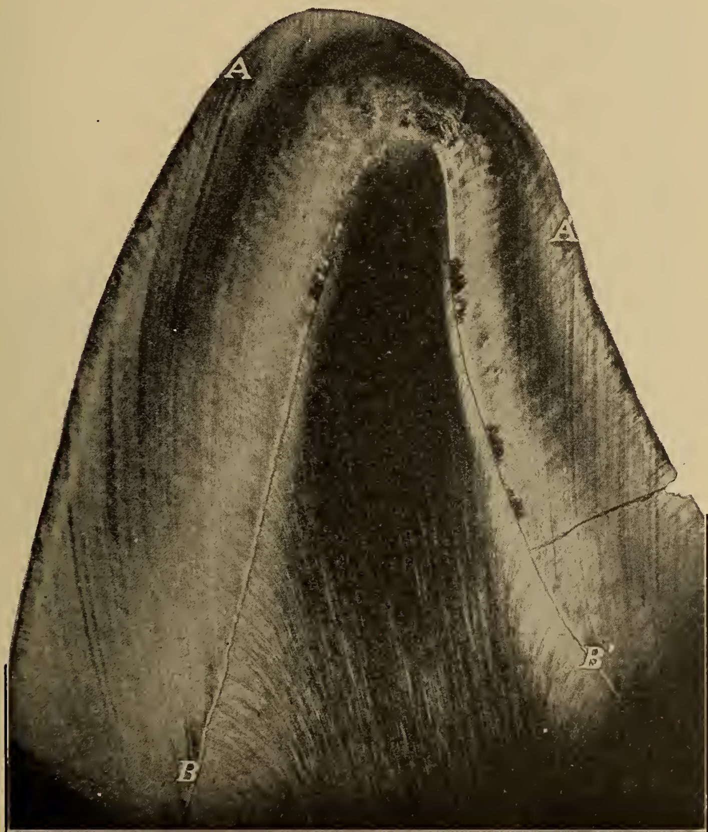


Fig. 39.—Incisor tip showing stratification or incremental lines. Rods at *A* were fully formed at the time the rods at *B* were beginning to form. (About 50 ×)

right angles to the zones. Fig. 38 shows the tip of an incisor in which the bands are very well marked. They are seen to begin at the dento-enamel junction on the incisal edge, and sweep in larger and larger zones around this point. Each band represents what was at one time the surface of the enamel already formed, and the line upon which formation was progressing. They are therefore truly incremental lines. The zones reach the surface of the enamel first at the point over the center of beginning calcification, and the succeeding bands extend from the surface of the enamel, near the occlusal, to the dento-enamel junction much farther apically,

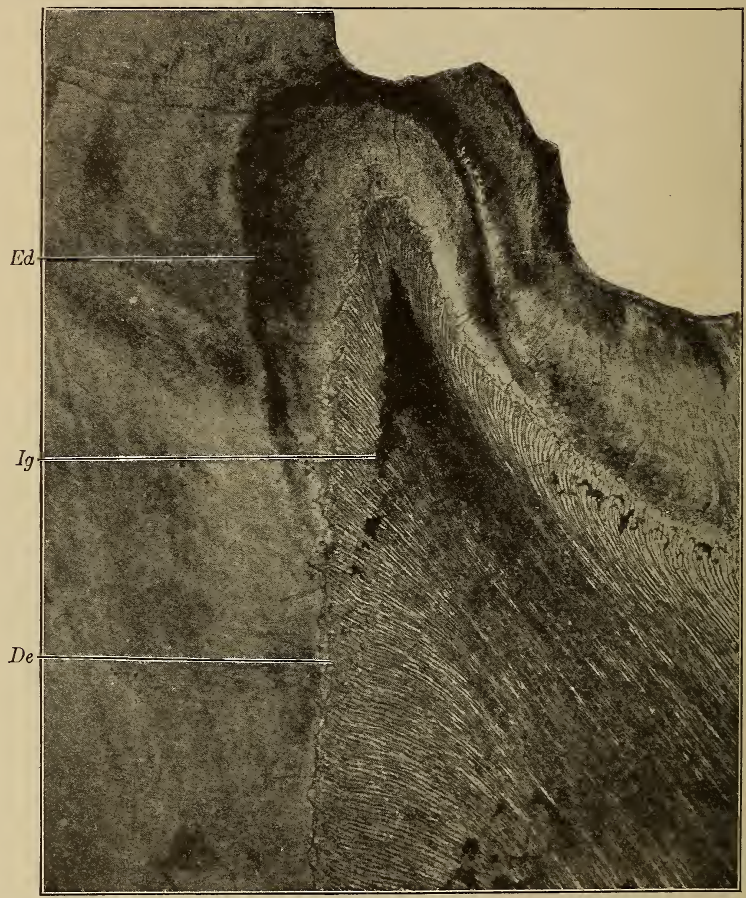


Fig. 40.—Stratification of enamel; the cusp of a bicuspid: *De*, dento-enamel junction; *Ed*, enamel defect showing in the heavy stratification band; *Ig*, interglobular spaces in the dentin. (About 40 ×)

and corresponding lines are seen on opposite sides of the section. In Fig. 39, the band which is at the surface at *A* and *A′* reaches the dento-enamel junction at *B* and *B′*. This means that when the enamel rods which form the surface at *A* were completed, the rods at *B* were just beginning to be formed at the dento-enamel junction. A layer of functioning ameloblasts occupied this position. The bands of Retzius are always curved and usually pass obliquely across the enamel rods, but are parallel neither with the dento-enamel junction or the surface of the enamel. As they pass toward the gingival the angle which they form with the axis of the tooth becomes greater. Any disturbance of nutrition which affects the formation of enamel is always shown in the increased distinctness of the bands (Fig. 40).

The bands of Retzius therefore form a record of the formation of the tissue, and by their study the points of beginning calcification and the manner of the development of the tooth crown may be followed. This will be considered again in connection with the grooves, pits, and natural defects of enamel.

FIG. 41.—Lines of Schreger. (About 5 ×)

Lines of Schreger.—These are lines appearing in the enamel extending from the dento-enamel junction to or toward the surface. They are caused by the direction in which the enamel rods are cut. They may be seen in sections, but are best shown by photographing the cut surface of the enamel by reflected light and with very low magnification. The rods are twisting about each other, and in one streak they are cut longitudinally, in the next obliquely, and the alternations of these directions cause the appearance of the lines (Fig. 41).

Nasmyth's Membrane (*The Enamel Cuticle.*)—There has been a vast amount of writing and fruitless speculation in regard to this structure. The facts which have led to all this speculation can be simply stated. If a freshly extracted tooth, that has not been exposed to wear, is decalcified or treated with dilute nitric acid

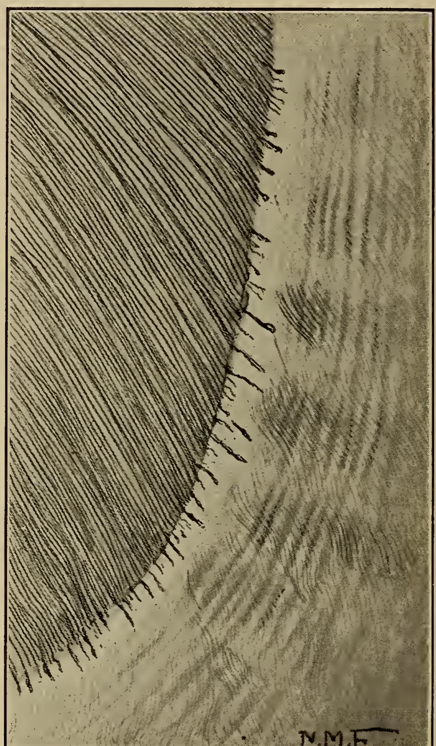


Fig. 42

(other acids may be used) a membrane can be floated from its surface which is found to be made up of two layers. (1) A clear structureless layer which was in contact with the surface of the enamel and bears the imprints of the ends of the enamel rods on its surface. (2) An outer cellular layer made up of a layer or layers of epithelial cells. Unfortunately the study of Nasmyth's membrane seems to have been made from extracted teeth and not from sections which retained the teeth and all of the supporting tissues in relation.

Two distinct explanations have been given to this structure:

(1) Owen and Tomes considered it as not epithelial but a deposit of coronal cementum on the surface of the enamel before the eruption of the tooth as occurs in the teeth of ungulates. (2) Huxley, Lent, Kölliker, Waldyer, Paul, Mummery and others have recognized its epithelial origin and described its structure in detail. All

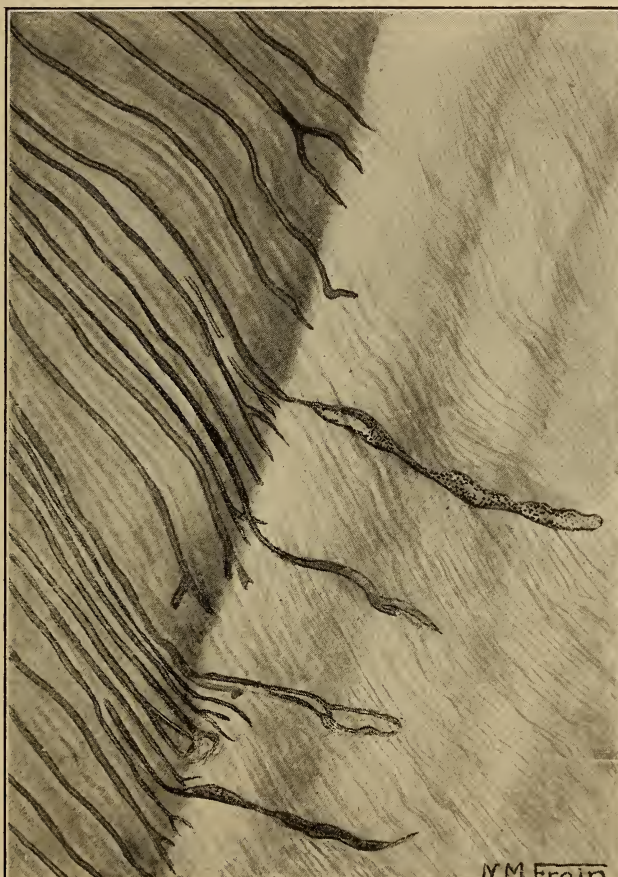


Fig. 43

have considered it as in some way related in origin to the enamel organ but as to the way in which it is formed or the nature of the relationship there is no agreement.

In the opinion of the writer, coronal cementum occurs on the enamel surface and in the grooves of the crowns of many human teeth but is in no way related to the structure described as Nasmyth's Membrane. On the other hand, while the structure is undoubtedly of epithelial character, he does not believe that it is related to the enamel organ or the formative epithelium of the enamel in origin.

On the eruption of the tooth the epithelium of the gingival fold, at least on the deeper portions is held firmly against the surface of the enamel by the pressure of the surrounding tissues, and the surface cells are quite firmly adherent to the surface of the enamel. The multiplication of epithelial cells in the deep portion of the gingival fold causes the epithelium to be pushed outward along the surface of the enamel and the layer separated from the surface of the enamel by the action of acid is this layer which has been separated from the epithelium lining the gingival space. In this connection decalcified sections with all of the tissues in relation should be studied and attention is called to the comparison of the structure of the gingival fold of the tooth and the nail fold of the finger nail.

Nasmyth's membrane undoubtedly has some important relations to normal and pathologic conditions, especially those beginning in the gingival space.

Enamel Spindles.[1]—Especially in the region of the cusps and the points where enamel formation begins in the calcification of the tooth peculiar spindle-like spaces are seen extending from the dento-enamel junction into the enamel. These have often been described, and much has been written in regard to them, but there is no agreement among investigators as to their cause or significance. They are apparently spaces in the interprismatic substance and between the enamel rods. They appear to communicate with dentinal tubules. In some cases at least, they appear to be filled with granular material. They are easily demonstrated, but not so easily explained.

[1] For further discussion of these structures the student is referred to Microscopic Anatomy of the Teeth by Mummery, p. 78 *et seq.*

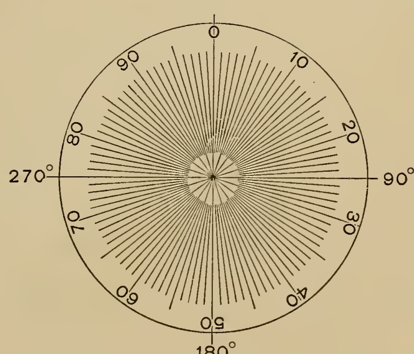
CHAPTER VI.

THE DIRECTION OF THE ENAMEL RODS IN THE TOOTH CROWN.

In describing the direction of the enamel rods and their arrangement in what may be called the architecture of the tooth crown, they are always considered as extending from the dento-enamel junction outward. This is not only convenient, but logical, as they are formed in that way, beginning at the dento-enamel junction and being completed at the surface. Enamel is formed from within outward, the cells which produce it lying outside of the tissue already formed, and there are many things about the arrangement of the rods and their relation to each other that are understood only when this is borne in mind.

The direction of the enamel rods is described by referring them to the horizontal and axial planes, which have been previously defined (page 35). The centigrade scale, that is, the division of the circle into one hundred equal arcs, is used because those familiar with instrument nomenclature are already familiar with these angles, and readily picture them.[1] When a rod is said to be inclined 12 centigrades occlusally from the horizontal plane, it means that if a plane at right angles to the long axis of the tooth is passed through the end of the rod at the dento-enamel junction, the rod

[1] In the centigrade division the circle is divided into one hundred parts, each called a centigrade. One centigrade is equal to 3.6 degrees of the astronomical circle, 25 centigrades to 90 degrees, $12\frac{1}{2}$ centigrades to 45 degrees. The cut gives a comparison of the two systems of measuring angles.



Centigrade division.

will lie to the occlusal of it and form an angle of 12 centigrades with it. In the same way, if a rod is said to be inclined 12 centigrades buccally from the mesiodistal plane, it means that if a plane parallel with the axis of the tooth, and extending from mesio to distal, is passed through the end of a rod at the dento-enamel junction, the rod will lie to the buccal of it, and form an angle of 12 centigrades with it. By a little practice with these terms the direction of the enamel rods can be very easily and clearly pictured to the mind.

The General Direction of Enamel Rods.—The general direction of the enamel rods has been variously described by different authors, but all of these general statements are very imperfect and often misleading. For instance, they are sometimes said to radiate from the center of the crown or the pulp chamber, but it will be seen that this does not apply to the rods which form the lingual slopes of the buccal cusps, or the buccal slopes of the lingual cusps of bicuspids and molars.

Again, they have been said to be, in general, perpendicular to the surface, but it will be found from the study of sections that there are very few places upon the surface where this is true, and that in many places they are far from perpendicular to the surface. From a study of sections it will be seen that the general arrangement of enamel rods, in the architecture of the tooth crown is such as to give the greatest strength to the perfect tissue, and to furnish the greatest resistance to abrasion in the use of the teeth for mastication. In a buccolingual section through a bicuspid (Fig. 44), beginning at the gingival line, the enamel is normally slightly overlapped by the cementum, and in the gingival third the rods are inclined more or less apically from the horizontal plane. The degree of inclination varies considerably. It may be as much as 12 centigrades, but is usually not more than 6. In general, the more convex the surface, the greater will be the inclination. At some point between the junction of the gingival and middle thirds and the middle of the middle third of the surface they are in the horizontal plane and at right angles to the axis of the tooth, and at this point they are usually very nearly perpendicular to the surface. Passing occlusally from this point, they incline more and more occlusally until in the occlusal third they reach an inclination of 18 to 20 centigrades occlusally from the horizontal.

The rods which form the tip of the buccal cusps do not reach the tip of the dentin cusp, but the buccal slope of the dentin. This

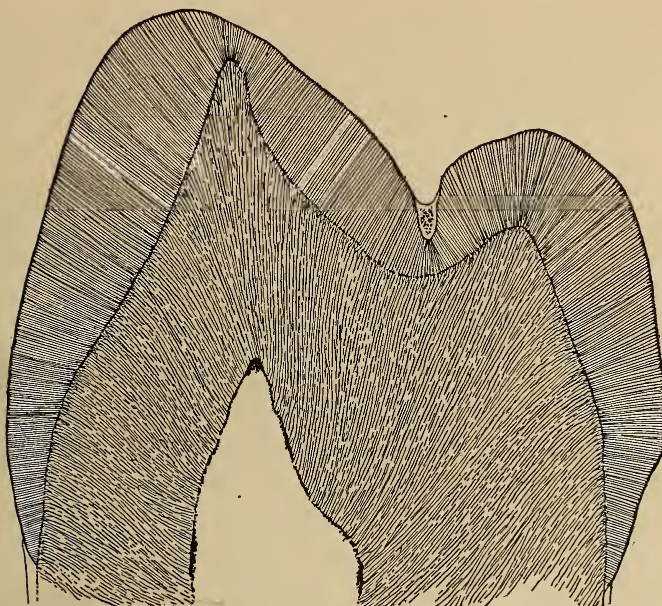


Fig. 44.—Diagram of enamel rod directions, from a photograph of a buccolingual section of an upper bicuspid.

Fig. 45.—Diagram of enamel rod directions, drawn from a mesiodistal section of a bicuspid.

becomes important, as will be seen later. Over the tip of the dentin cusp the rods are in the axial plane, but in this position they are usually very much twisted. Passing down the lingual slope, they become more and more inclined lingually from the mesio-

Fig. 46.—Disturbance of enamel rod directions on labial surface of a cuspid. (About 80 ×)

distal axial plane, and the degree of inclination is related to the height of the cusp—the taller the cusp, the greater the inclination. At the developmental groove or pit they meet the rods of the lingual cups, which are inclined in the opposite direction.

Fig. 47.—Disturbance of enamel rod directions on lingual surface of same tooth as Fig. 48. (About 80 ×)

In a mesiodistal section (Fig. 45) the plan of arrangement will be seen to be the same, the tip of the marginal ridge corresponding to the tip of the cusp. In an incisor the arrangement is similar, the lingual marginal ridge corresponding to a rudimentary cusp. This general plan should be studied in several sections of the various classes of teeth before the rod direction is studied more minutely.

Effect of Hypoplasia.—Whenever a hypoplasia groove appears upon the surface, the rod directions will be found to be more or less disturbed. Fig. 46 shows a position on the labial surface of a cuspid. In this position the disturbance of the enamel rod direction is very marked. The rods tend to be in whorls and the structure is more or less deficient. On the lingual side of the same section (Fig. 47) the disturbance in structure is so great that it is difficult to make out the rod direction. Many such areas will be found in sections. Some condition which has affected the nutrition of the enamel-forming cells results in a local disturbance of the structural elements.

SPECIAL AREAS.

The Gingival Third.—There is much variation in enamel rod direction in different teeth as the gingival line is approached. The inclination apically from the horizontal may be very great, as much as 12 to 15 centigrades in some instances, as in Fig. 48, but this is exceptional. It may be very slight, or the rods may be almost in the horizontal plane. The direction of the rods in these areas become very important in the preparation of the gingival wall of proximal cavities, and cavities in the gingival third of buccal and labial surfaces.

The Tips of the Cusps.—In studying the rod directions in the region of the cusps and marginal ridges, it must be borne in mind that the formation of enamel begins at the dento-enamel junction, at separate points, and that the growth is recorded in the tissue by the bands of Retzius, each band having been at one time the surface of the enamel cap then formed. In a buccolingual section the formation of the buccal and lingual cusps will be shown (Chapter IX). While the little caps are growing they are being carried apart by the growth of the dental papilla and enamel organ, until the calcifications unite at the dento-enamel junction. When this occurs the dental papilla has reached its maximum mesiodistal diameter. The enamel organ, however, will continue to grow, and as the rods are completed first just over the tip of the dentin cusp, the continued growth causes an increase in the inclination of the

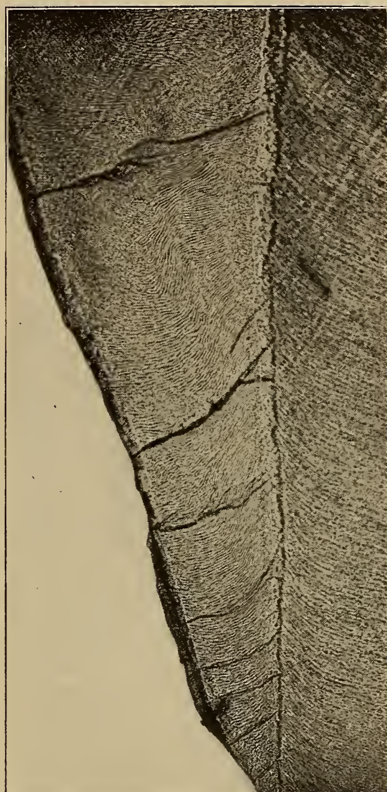


Fig. 48.—Direction of enamel rods in the gingival third.

rods in their outer portion. This often leads to a curving of the rods at their outer portion.

CHAPTER VII.

THE RELATION OF THE STRUCTURE TO THE CUTTING OF THE ENAMEL.

There are two methods of cutting enamel—to chop or cleave it, and to shave or plane it.

Cleaving or Chopping Enamel.—In the cleavage of the enamel the action of the instrument more nearly resembles that of splitting ice than that of splitting wood. The ax for splitting wood is strongly wedge-shaped, and the wedge pries the fibers apart. In splitting ice a small nick is made on the surface and then a sharp blow cracks the ice in the direction of the cleavage. In a similar way the chisel applied to the surface of the enamel makes a slight scratch or bearing on the surface, and the force applied at a slight angle to the direction of the rods cracks the tissue through in the rod direction. The bevel of the instrument is designed to give strength and keenness of edge, not to act as a wedge. In order to cleave the enamel it is always necessary that there be a break or opening in the tissue, and usually that the dentin be removed from under it. Only a small portion can be split off at a time. The edge of the chisel should be placed on the enamel a quarter or half a millimeter from the opening, rarely more, and so piece after piece is split into the cavity. Fig. 49 shows a section of enamel. The edge of the chisel is placed at 1, with the shaft in the relation to enamel rod direction indicated; a tap of a steel mallet will split off a piece, and the chisel is moved back to position 2 and a second piece is split off. Undermined enamel will split easily in this way. As soon as a point is reached where the enamel rests on sound dentin, it is recognized by the resistance. Straight enamel can be split off from sound dentin without difficulty if attacked in the proper way, but if the inner portion is gnarled and twisted, it can only be cleaved by removing the dentin from under it. Such enamel, if resting on dentin, will split as far as the rods are straight; but where they begin to twist they will break off, leaving a portion which is very difficult to remove by attacking it from the surface. If the dentin is removed from under gnarled enamel, it will crack through in an irregular way, following the general direction of the rods.

In preparing teeth for crowns it is often necessary to remove a large amount of enamel. This is always more efficiently accomplished by the intelligent use of sharp instruments than by force alone. The enamel on axial surfaces, especially in the gingival

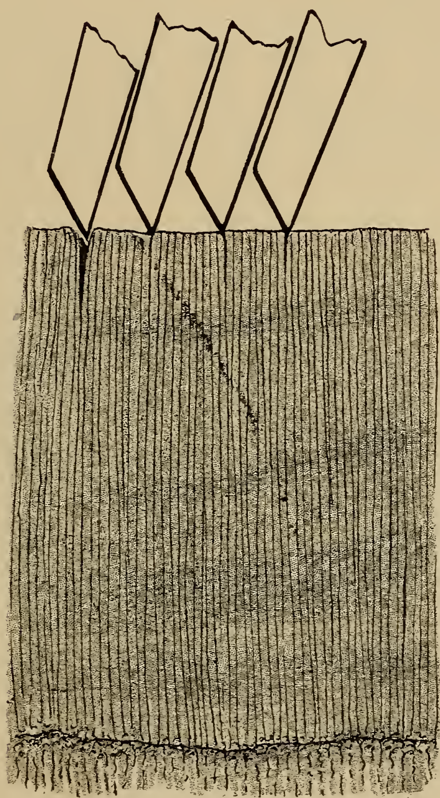


Fig. 49.—Position of chisel in cleaving enamel.

half of the crown, is usually straight, and if a cleavage line can once be established, the enamel can be more easily and rapidly removed by splitting it off piece after piece than in any other way. In doing this a straight or contra-angled chisel is often the most efficient instrument, and it must be remembered that the "root trimmers" are more properly called "enamel cleavers," and that they are used to cleave the enamel, not to scrape or hoe it off, their form being adapted to give a strong palm grasp of the instrument.

Fig. 50 illustrates the use of the enamel cleaver for the removal of gingival enamel from an axial surface. The line of cleavage being established, the edge of the instrument is placed on the

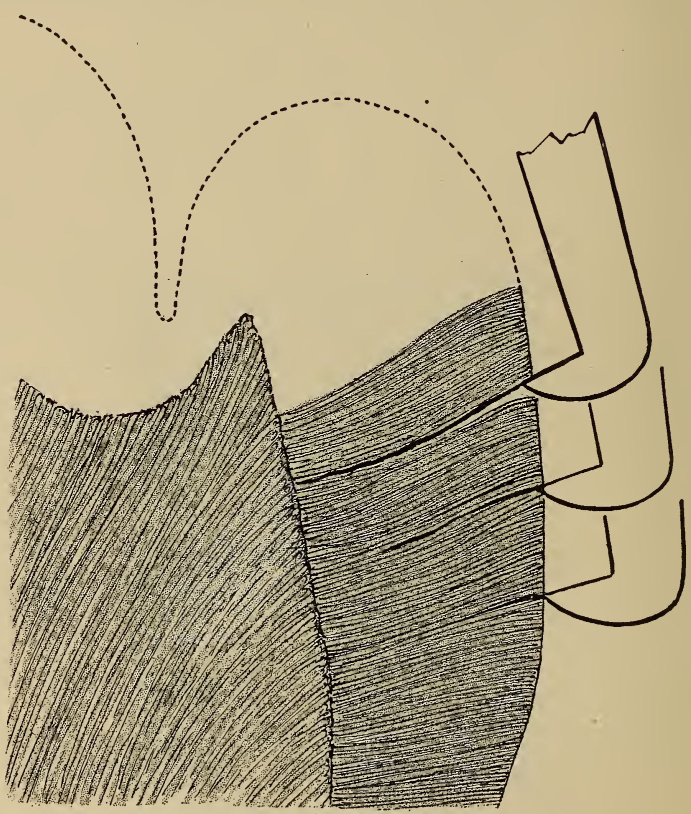


Fig. 50.—The use of enamel cleaver in removing enamel.

enamel half a millimeter from the broken edge, and the force, which should be strong, quick, and sharp, is applied in the direction indicated, and piece after piece is split off, progressing from the occlusal toward the gingival. In preparing the wall of a cavity the outline form should be attained by cleavage, and this is the first step in the preparation of the cavity.

After the enamel has been removed by cleavage to the point where the margin is to be laid, the wall must be completed by cutting the enamel in an entirely different way.

Planing or Shaving Enamel.—In this manner of cutting enamel the tissue is removed without reference to the rod direction, and without injury to its structure (Figs. 51, 52, and 53). The chisel is used like the blade of a plane. The cutting edge is placed against the surface with the shaft of the instrument almost parallel to it, and the tissue is shaved away. In this way the rods that have been cracked apart by the cleavage are removed, and the walls arranged in terms of its structural elements so as to gain the required strength of margin.

Sharp Instruments.—Chisels and hatchets for use in cleaving or planing enamel must be keenly sharp. If a dull edge is placed on

Fig. 51

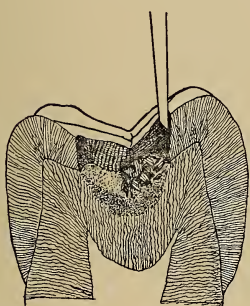


Fig. 52

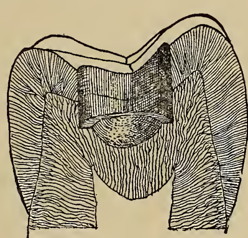
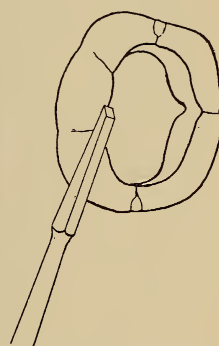


Fig. 53



Figs. 51, 52, and 53.—The use of the chisel in planing or shaving enamel. (Black.)

the surface of the enamel it will rest across the ends of many rods, and force applied will only crumble them, but will not split the tissue. The edge must be keen (Fig. 54), so as to engage between the rods and so start the cleavage. Cutting instruments as furnished by dental supply houses are not tempered hard enough to hold an edge. There is no fault to be found with the supply houses for this, for they make them as the dentist wants them, and any dealer will furnish hard-tempered instruments if they are ordered. To use hand instruments successfully in cutting enamel, the stock instruments must either be retempered or they must be ordered hard tempered. The cutting edge of the blade of an enamel instrument should be straw-colored when tempered.

The chisel and hatchets are the instruments for removing enamel.

The burr is the instrument for removing hard dentin. When the burr is used on enamel it should be remembered that it is used as a revolving chisel. It is by the thoughtful use of hand instruments

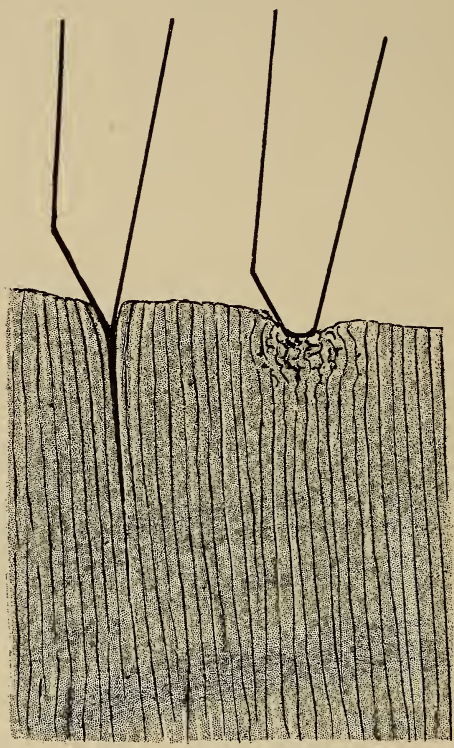
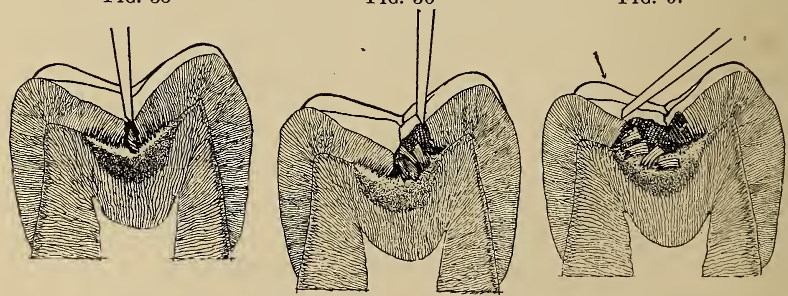


Fig. 54.—The relation of the edge of a sharp and a dull chisel.

Fig. 55

Fig. 56

Fig. 57



Figs. 55, 56, and 57.—The use of the chisel in cleaving enamel. Opening an occlusal cavity. (Black.)

that knowledge of enamel rod direction is gained, and only by the use of them can the enamel walls be prepared in terms of their structural elements. In cleaving undermined enamel the edge may be used either with a pulling or a pushing motion. For instance, in opening a cavity in the occlusal surface of a bicuspid, the buccal portion of undermined enamel is split off by placing the instrument as shown in Figs. 55 and 56. The bevel of the blade is held toward the cavity and the shaft of the instrument at a slight angle to the rod direction, and the force is applied in the direction of the shaft. The lingual portion may be removed by placing the instrument as indicated in Fig. 57, the bevel of the blade away from the cavity and the force applied in the direction of the bevel by a pulling force in the direction of the shaft. This is the way in which force is applied on enamel cleavers. The pitch of the bevel in an enamel cleaver and its relation to the shaft of the instrument is extremely important, and the efficiency of an instrument may easily be ruined by careless honing. Every time a cutting instrument is applied to the enamel it must be done with a knowledge of the relation of the cutting edge and the force to the direction of the enamel rods, until it becomes entirely automatic. The author emphatically believes that the acquirement of this knowledge and skill will do more to increase facility and success in the preparation of cavity walls than any other manipulative factor. The preparation of enamel walls requires the continual application of the knowledge of enamel structure. Enamel is a very hard tissue, but it is composed of structural elements, and walls prepared without reference to them will prove their own weakness.

CHAPTER VIII.

THE STRUCTURAL REQUIREMENTS FOR STRONG ENAMEL WALLS.

From the consideration of the physical character of the enamel, its structural elements and their properties, it is evident that the strength of any enamel wall is dependent upon the arrangement of the rods in the tissue which makes up the walls and their relation to the dentin. Certain requirements for strength can be clearly stated, and these are applicable to all enamel walls. They cannot always be secured with equal facility or perfection, but in proportion as these principles are observed and attained the wall will be strong; as they are imperfectly attained or ignored the wall will be weak and unreliable. When these conditions are understood very many failures can be clearly seen to have been the result of their neglect.

Structural Requirements.—1. The enamel must rest upon sound dentin.

2. The rods which form the cavosurface angle must have their inner ends resting upon sound dentin.

3. The rods which form the cavosurface angle must be supported by a portion of enamel in which the inner ends of the rods rest on sound dentin and the outer ends are covered by the filling material.

4. The cavosurface angle[1] must be trimmed or bevelled so that the margin will not be liable to injury in condensing the filling material against it (Fig. 58).

These requirements should be considered one by one.

The Enamel Must Rest upon Sound Dentin.—That is, the enamel plate must have the support of sound dentin, and all portions which are undermined by the removal of dentin must be cut away. When the inner ends of the rods which form the enamel plate rest upon sound dentin, the elasticity of the dentin gives to the enamel a certain degree of elasticity, but the enamel itself without this support

[1] The cavosurface angle is defined as the angle formed by the surface of the tooth and the wall of the cavity.

is extremely brittle. A force that causes it to give will crack it through its entire thickness. No filling material or substitute for the lost dentin can restore the original conditions. Figs. 58 and 59 illustrate these requirements. The enamel plate *a, b, c, d* rests upon sound dentin. The rods which form the cavosurface angle at *b* run uninterruptedly to the dentin, and their inner ends rest on it

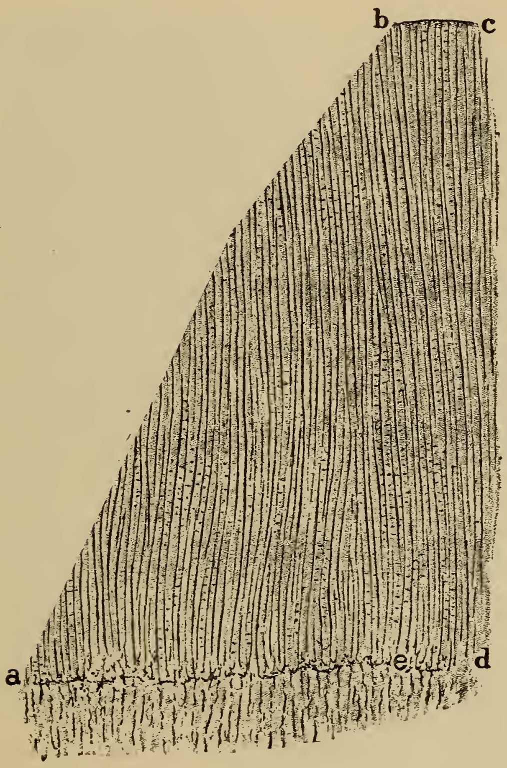


Fig. 58.—The structural requirements for a strong enamel wall.

at *e*. The rods, *b, e* are also supported by a portion of enamel, *a, b, e,* made up of rods whose inner ends rest upon the dentin and whose outer ends are covered in by the filling material, altogether supporting the marginal rods like a buttress. And the cavosurface angle is bevelled, including from $\frac{1}{3}$ to $\frac{1}{5}$ of the enamel wall, so as to remove the sharp corner which would be in danger of crumbling under an instrument. An enamel wall should be considered no stronger after the filling is inserted than it was before. Moreover, when the dentin has been decalcified or destroyed by the action of caries, the acid which has decalcified the dentin has also acted upon the enamel, dissolving the cementing substance from between the rods, from within outward, often to a great extent, and the structure is very imperfect. Enamel that has been so weakened

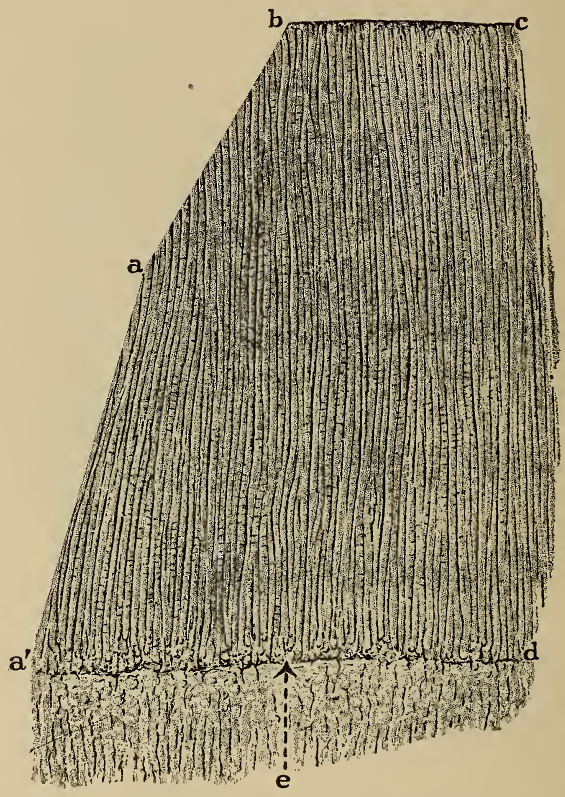


Fig. 59.—The structural requirements for a strong enamel wall: *a*, *b*, the level of the cavosurface angle. The rods forming the margin of the cavity at *b* reach the dentin at *e*, and are supported by the portion *a*, *b*, *e*.

will not withstand the force of mastication, and sooner or later will crack or break away from the filling material. It should be removed and the wall formed in tissue whose structure is perfect. Occasionally cases arise where an operator decides to leave some unsupported enamel, but its weakness and the possibility of restoring it if it breaks away without destroying the original operation must always be considered. It is sometimes supposed that it is only necessary to have sound enamel resting on sound dentin, but by looking at Figs. 60 and 61 it will be seen that the first requirement may be present, but not the second. In these illustrations the enamel plate is resting on sound dentin, but the tissue has been cut in such

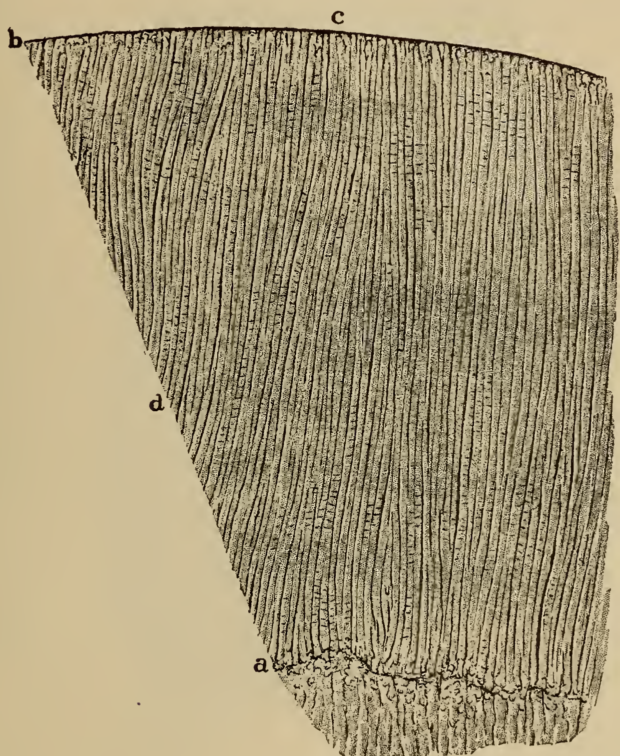


Fig. 60.—Improperly prepared enamel wall. The portion *a, b, c* has the inner ends of the rods cut off and they do not reach the dentin.

a way that the inner ends of the rods have been cut off. The rods that form the cavosurface angle do not extend to the dentin, but run out on the cavity wall at *d*, and the portion *a, b, c* is held together only by the cementing substance. This is not strong enough to sustain the force necessary to condense the filling material or the forces received upon the surface of the tooth after the filling is completed. It will crack on the line of the cementing substance and chip out. The inclination of the entire wall must be increased to a little more than to reach the rod direction. Such a wall as this may easily be made, in preparing a cavity wall, with a stone or a burr, but would not be liable to be formed with hand instruments. Such walls as this account for the chipping of many margins

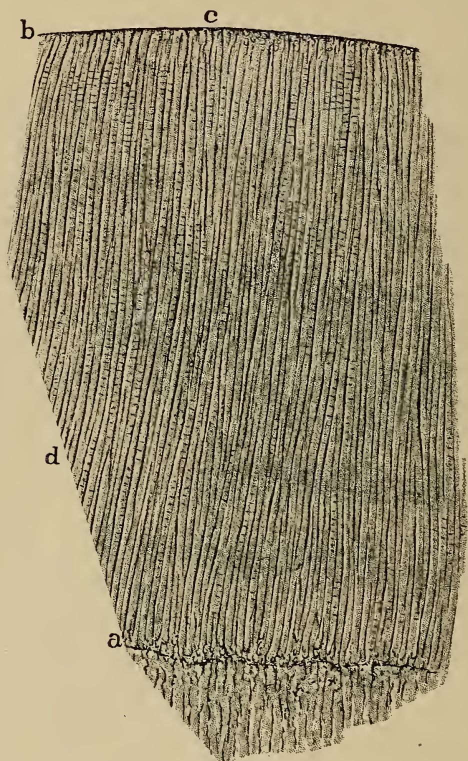


Fig. 61.—Improperly prepared enamel wall. The portion *a*, *b*, *c* is not supported by dentin.

and the failure of fillings along the gingival wall. The tissue is cracked to pieces in inserting the filling material, and the pieces fall out later. This occurs often in the gingival walls of compound cavities.

The Rods Forming the Cavosurface Angle Must be Supported.— This is the key to strong enamel walls. The more perfect the support the stronger the wall. If an enamel wall is cut exactly in the direction of the rods, as in Fig. 62, the rods forming the margin are held together only by cementing substance, and a comparatively slight force on the surface in the direction toward the cavity will break them off. If the same wall is trimmed, as indicated by the line, the same force would do no damage, as the rods which receive it are supported by the portion which is covered by the filling

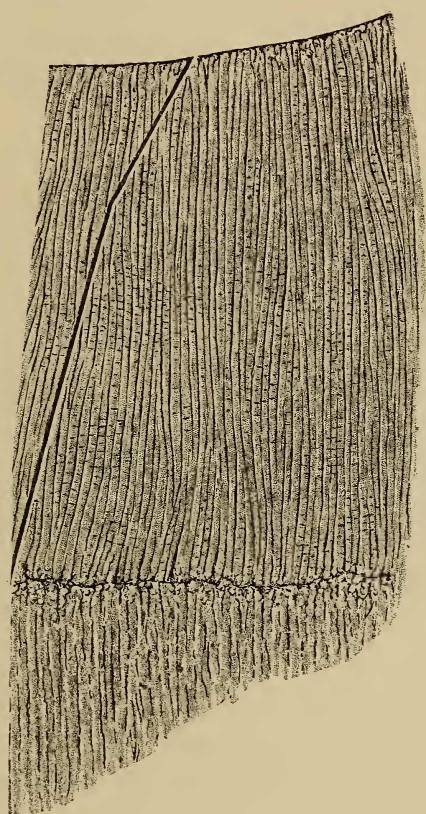


Fig. 62.—Enamel wall cut in the direction of the rods. The marginal rods are not supported. It should be trimmed in the line indicated.

material. It is interesting to note that in the wearing down of the enamel by use, nature provides the same support for the rods which form the angle of the worn and tooth surfaces. Fig. 63 shows the tip of a worn incisor. The rods at *A* reach the dentin at *C* and are supported by the portion *A, B, C*. When caries occurs on an abraded surface it starts by the rods at the dento-enamel junction, chipping out and forming a protected niche for the lodgement of a colony.

Bevel the Cavosurface Angle.—It is not always necessary to bevel the cavosurface angle where the rods are inclined toward the cavity. In such places the rods forming the margin are well supported and the angle need not be bevelled unless it is so sharp that it would be in danger of being injured.

There are two reasons for bevelling the cavosurface angle: (1) To protect a sharp angle from injury; (2) to gain support for the

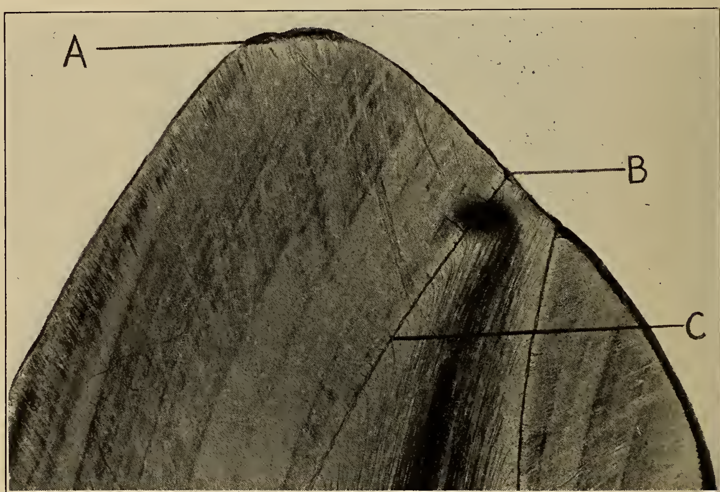


Fig. 63.—The tip of a worn incisor. The rods forming the angle at *A* reach the dentin at *C*, and are supported by the piece *A*, *B*, *C*.

marginal rods. The first occurs where the enamel rods are inclined toward the cavity, the second where they are inclined away from the cavity.

Classes of Cavities.—From a consideration of the direction of the enamel rods in the tooth crown, and the positions where caries begins on the enamel, enamel walls may be divided, according to their structural type, into two classes (Fig. 64):

1. Those in which the enamel rods are inclined toward the cavity, characteristic of cavities on occlusal surfaces and cavities beginning in fissures and pits.

2. Those in which the enamel rods are inclined away from the cavity, characteristic of cavities on smooth surfaces.

In the first class it is comparatively easy to obtain a strong margin, and this is fortunate, for when the filling is completed the margin will be subjected to the full force of mastication. In the second it is comparatively difficult to obtain a strong margin, but only sufficient strength is required to withstand the force of condensing the filling material, as after the filling is completed it will be obliged to withstand little force from mastication.

From a careful observation of the failures of fillings (his own and those of other operators), the author believes a very large

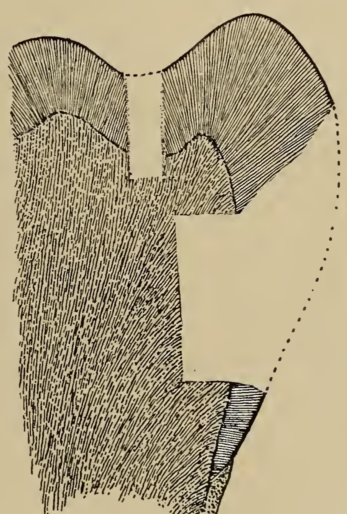


Fig. 64.—The two classes of cavities. Those with the rods inclined toward the cavity, and those with the rods inclined away from the cavity.

number are due to structurally imperfect enamel walls. A study of enamel structure as related to cavity preparation will do more to improve the quality of the operation and to increase the facility of its execution than any one factor. This study is a clinical study guided by examination of the microscopic structure of the tissue. In operating at the chair the detail of enamel rod direction as it is applied to cavity preparation is learned, but to do so hand instruments must be used and a sufficient knowledge of the tissue must have been acquired to think of it always in their use in terms of its structural elements.

The steps in the preparation of an enamel wall are:

1. The cleavage of the enamel until the outline form of the cavity is reached.
2. The trimming of the enamel walls.
3. The preparation of the margins.

Fig. 65.—Occlusal fissure in an upper bicuspid, showing direction of rods. (About 80 ×)

Every enamel wall should be prepared according to these steps. The first not only removes the tissue more or less disintegrated and weakened by caries, but also places the margin of the filling in a position where it is not likely to be covered by the growth of a colony of bacteria. It also determines the direction of the enamel rods so that the walls can be completed in terms of its structural elements.

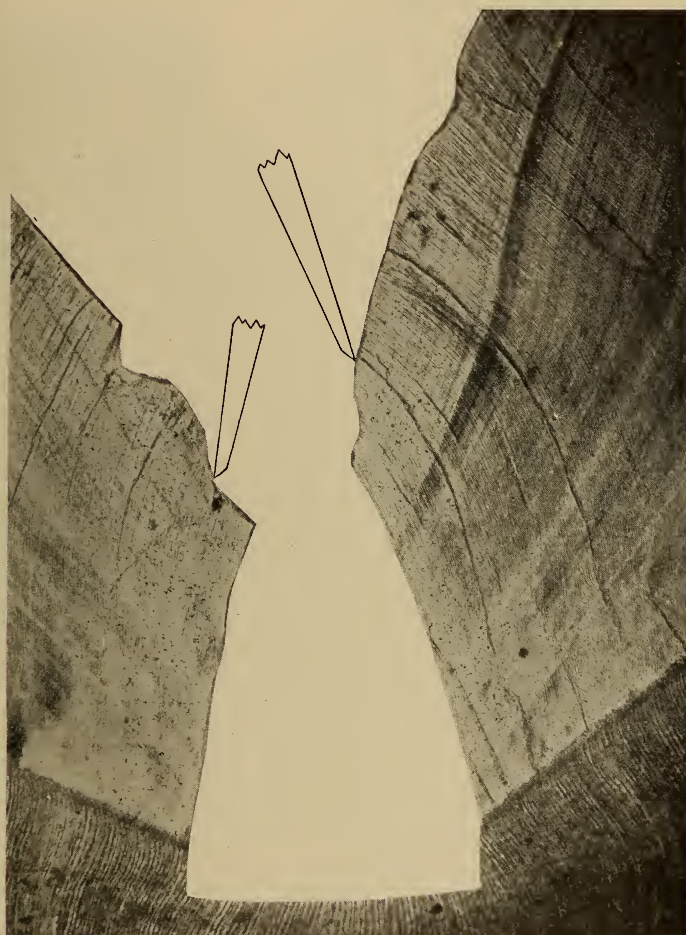


Fig. 66.—The same section as Fig. 65, showing the position of the chisel in cleaving the enamel to open the cavity.

The second step is accomplished by the shaving or planing process, and should always increase the inclination of the entire enamel wall slightly, so as to extend a little beyond the rod directions, and remove the portions that have been cracked or splintered by the cleavage. After cleavage the enamel wall will usually have a more or less whitish look. This is caused by the cracking of the cementing substance between the rods. The light is refracted by

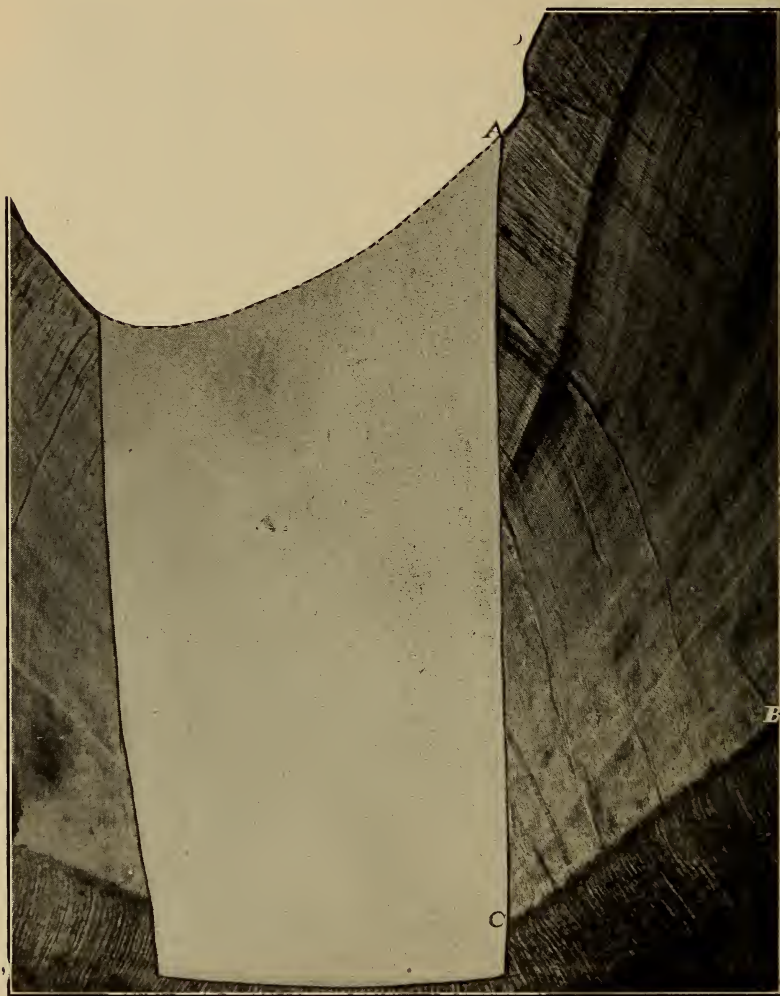
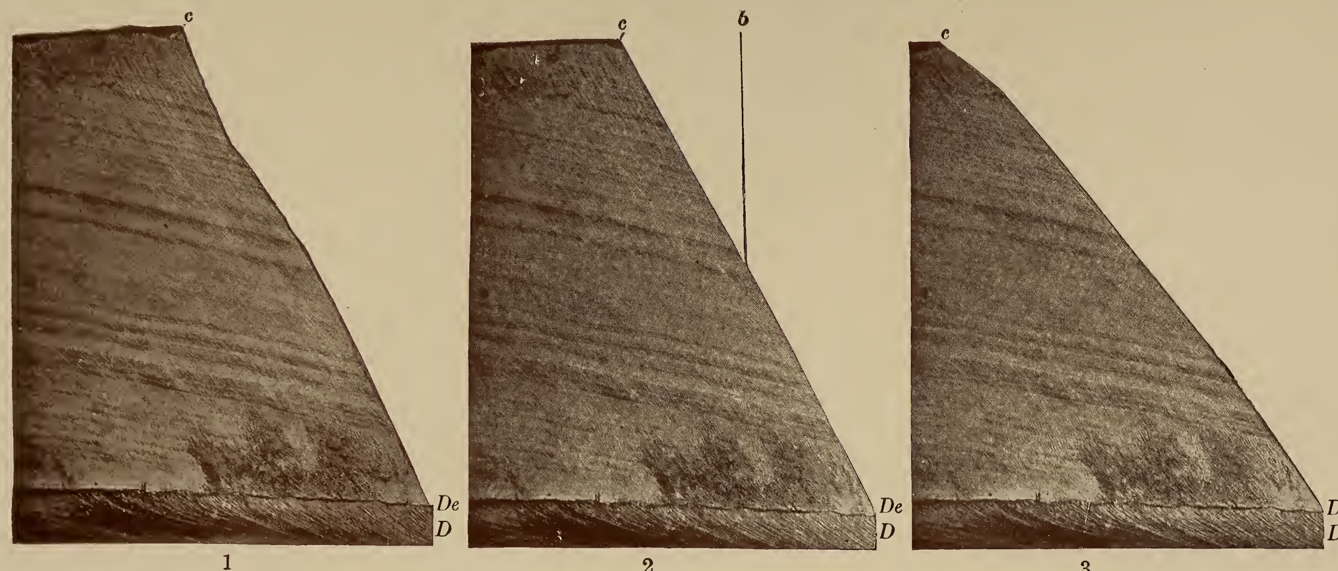


Fig. 67.—Preparation of enamel walls in occlusal fissure cavities (the same as Figs. 65 and 66).

the air in these microscopic spaces and imparts this whitish or snowy look to the tissue. These portions are removed by planing or shaving, and the tissue obtains its bluish, translucent appearance.

PLATE VII



Preparation of Enamel Wall in Straight Enamel.

1, enamel wall as cleaved, showing breaking across rods; 2, wall smoothed but not extended; some rods do not reach the dentin, but their inner ends are cut off at *b*; 3, correctly trimmed and the cavosurface angle slightly bevelled; the inclination of the enamel rods is too great to make a good enamel wall in this position; *c*, cavosurface angle; *De*, dento-enamel junction; *D*, dentin; *b*, point at which inner ends of rods are cut off. (About 80 X.)

The third step is also accomplished by the planing process, and should be carried out with two objects in mind: (1) To so form the cavosurface angle that the tissue will not be liable to injury in the condensation of the filling material against it, and (2) to leave rods whose outer ends will be covered by the filling material to support those which form the actual margin of the cavity.

The steps in the preparation of enamel walls may be made more clear by photomicrographs. Plate VII shows a portion of enamel close to a carious cavity which is to be extended to the left. The chisel is placed close to the margin and the portion is split off. The

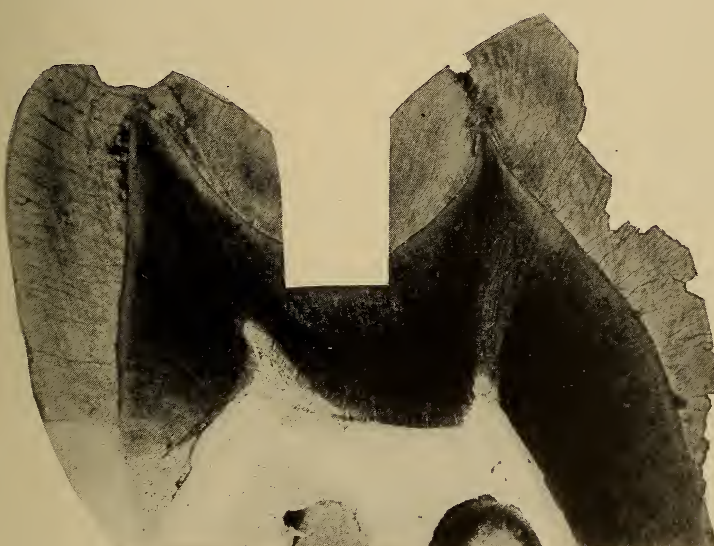


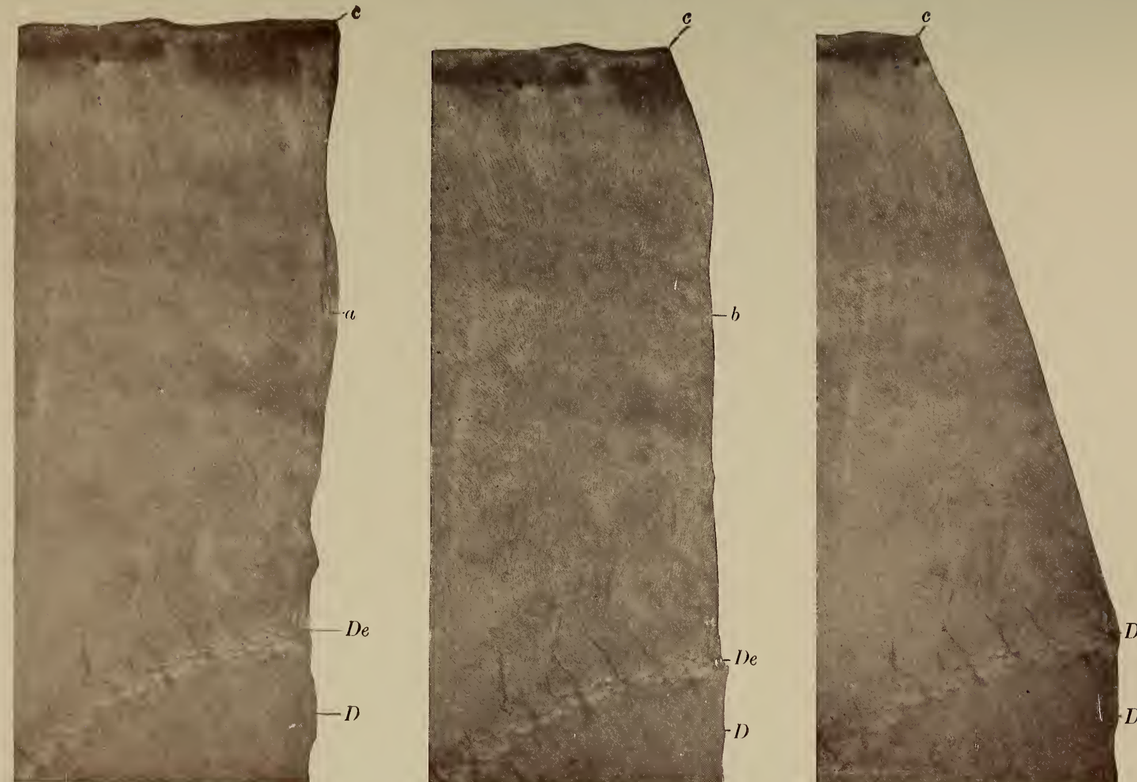
FIG. 68.—The relation of the cavity to the crown (the same as Figs. 66 and 67).

wall then appears whitish, for, as is seen, the cementing substance has cracked in several places, disturbing the structure, and in several places rods have been broken across. The wall must now be planed so as to increase the inclination of the entire wall slightly, and finally the cavosurface angle must be bevelled, involving from $\frac{1}{5}$ to $\frac{1}{3}$ of the thickness of the enamel wall to give support to the rods forming the margins. In this case the rods are straight and parallel, but in Plate VIII they are twisted. If the dentin is removed from under this enamel and the chisel placed as indicated, the portion will be split out, but not only has the tissue been splintered, but a considerable portion is left in which the rods have been broken across. By feeling of the margin with the chisel this can easily be determined, and the angle of the wall must be increased by planing so as to leave the wall in the position shown in Plate VIII, 3, and finally the cavosurface angle must be bevelled.

Fig. 69.—The trimming of the walls instead of lapping the filling material on the slope of the cusps.

Preparation of Simple Occlusal Cavities.—Caries often begins in the mesial and distal pits of the upper bicuspids, and in preparing the cavities for filling they must be united. Fig. 65 is a buccolingual section through a first superior bicuspid. Suppose caries has reached the dento-enamel junction in both the mesial and distal pits, and they are to be united along the groove. A small spear drill is carried into the mesial pit until the dento-enamel junction is reached, then a small inverted cone burr is carried into the dentin just under the enamel and drawn from the dentin to

PLATE VIII



1 2 3

Preparation of Enamel Wall in Gnarled Enamel.

1, enamel wall as cleaved, showing breaking across rods and slivering at *a*. 2, wall as smooth, but not extended to remove short rods whose inner ends are cut off at *b*. 3, wall extended and trimmed to a position of strength. *D*, dentin; *De*, dento-enamel junction; *c*, cavosurface angle; *b*, point where inner ends of rods are cut off; *a*, slivering of the tissue. (About 80 X.)

the surface of the enamel. When a narrow cut has been made from the mesial to the distal pit, a chisel placed at the edge of the opening will split out the enamel as indicated in Fig. 71. Now the walls must be planed so as to bring the buccal and lingual walls into the axial plane, and the structural requirements will have

Fig. 70.—Caries beginning in an occlusal defect of a molar. (About 80 ×)

been completed (Fig. 67). Fig. 68 shows the relation of the cavity to the crown.

It has often been advised to allow the filling to extend on to the natural slopes of the cusps, as indicated in Fig. 69. It will be seen, however, that a stronger enamel wall and a stronger edge of filling material will be obtained if the enamel wall is bevelled to the point where the margin of the filling is desired and the filling finished to this position.

Fig. 70 shows a buccolingual section through a molar with a small cavity in a mesial pit. Caries has undermined the enamel

Fig. 71.—The preparation of the enamel walls of the cavity shown in Fig. 70.

slightly toward the buccal, but has attacked the enamel on the surface, extending toward the lingual farther than the enamel has been undermined at the dento-enamel junction. Applying the chisel to the surface, the undermined enamel is split away, as is indicated in Fig. 71. The buccal wall is planed until it is in the axial plane, and the cavosurface angle bevelled. It is not necessary to extend the cavity to the lingual beyond the point where sound dentin is reached, but the disintegrated enamel on

FIG. 72.—The relation of the cavity to the crown (the same section was shown in Figs. 70 and 71).

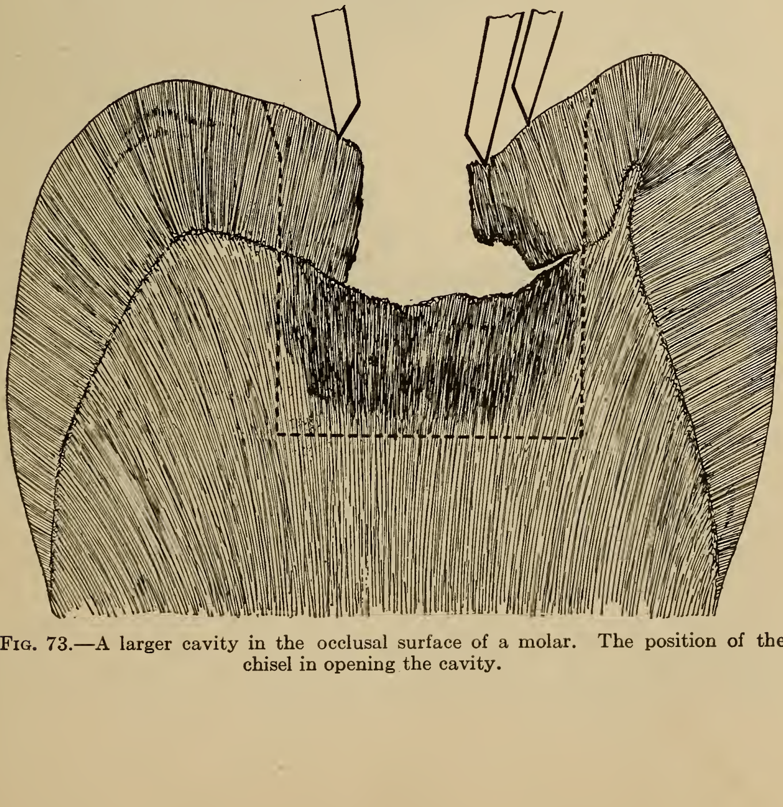


FIG. 73.—A larger cavity in the occlusal surface of a molar. The position of the chisel in opening the cavity.

the surface must be removed. The enamel wall is therefore inclined about 6 centigrades lingually from the axial plane, and it is not necessary to bevel the cavosurface angle. The rods are inclined toward the cavity, the rods forming the margins are

Fig. 74.—A gingival third cavity in a bicuspid, showing the cleavage of the occlusal and gingival walls as cleaved.

well supported, and the cavosurface angle is not so sharp as to be endangered in condensing filling material. Fig. 72 shows the relation of the cavity to the crown.

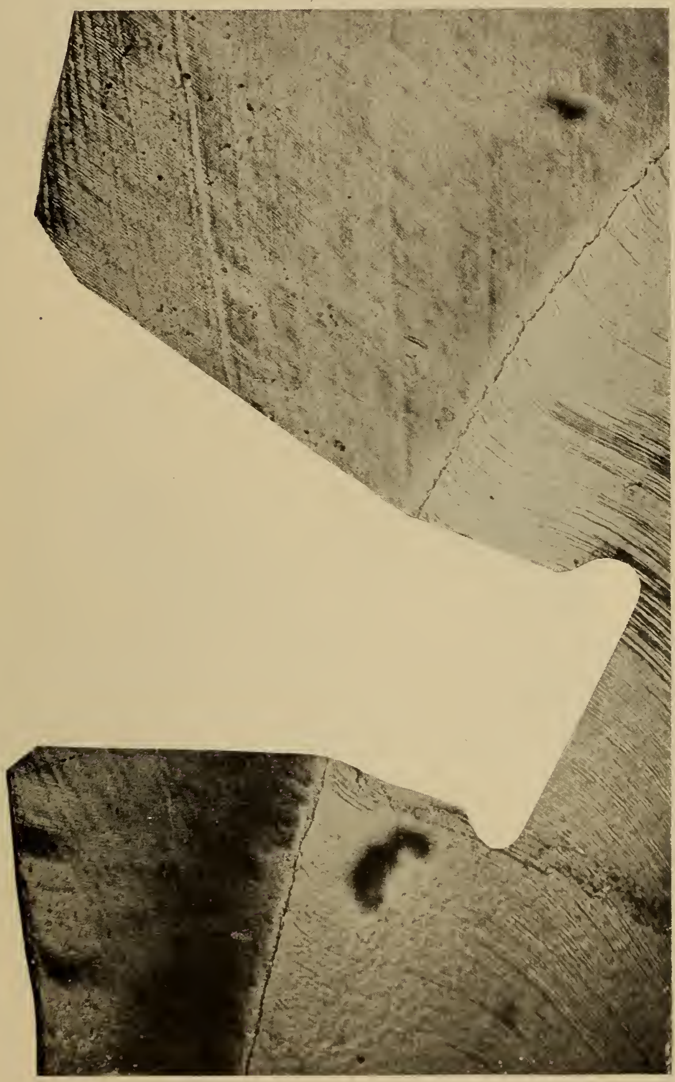


Fig. 75.—The preparation of the cavity shown in Fig. 74.

All occlusal defects should be filled as soon as the decay has reached the dento-enamel junction, as all progress of the disease beyond that point requires sacrifice of tissue which otherwise would be saved, and the enamel wall becomes less and less strong. Fig. 73 shows a much more extensive occlusal cavity, one that has been neglected until the enamel has been broken in, and as a result there was much unnecessary loss of tooth structure. The chisel is applied to the surface as indicated, and the undermined enamel broken down until the sound dentin is reached. On the buccal, the enamel wall is cut to the axial plane, and the cavosurface angle bevelled. If the decay in the dentin had reached the tip of the dentin cusp, it would be necessary to remove the tip of the enamel cusp and incline the wall about 8 centigrades buccally

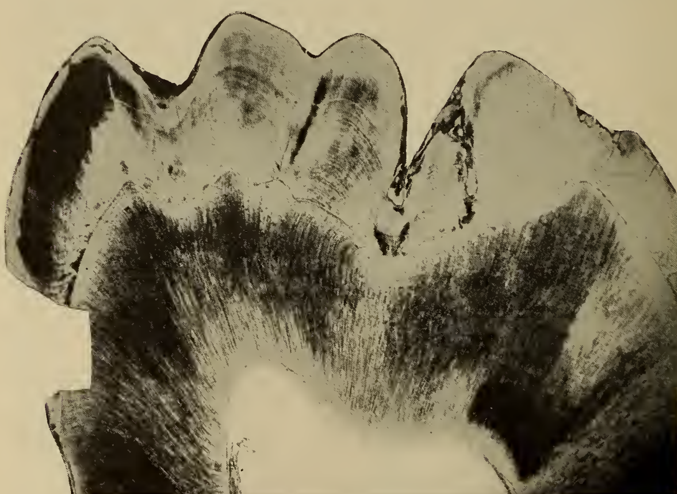


Fig. 76.—A gingival third cavity in a molar.

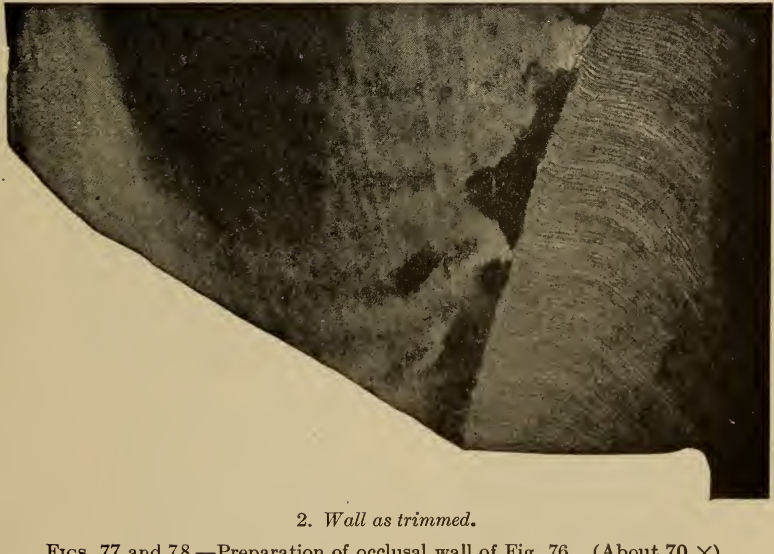
from the axial plane, in order to obtain a strong wall, and then the cusp would be replaced by filling material. On the lingual the undermined enamel is removed, and the wall inclined slightly lingually from the axial plane and the cavosurface angle bevelled a little. Fig. 73 shows the relation of the cavity to the crown.

Gingival Third Cavities.—Fig. 74 is a buccolingual section of a superior bicuspid, showing a break in the enamel in the position of a gingival third cavity. The occlusal wall is cleaved to find the enamel rod direction, then planed to increase the inclination slightly, leaving it inclined about 8 centigrades occlusally from the horizontal plane, and the cavosurface angle bevelled to obtain support

FIG. 77

1. *Wall as cleaved.*

FIG. 78



2. *Wall as trimmed.*

FIGS. 77 and 78.—Preparation of occlusal wall of Fig. 76. (About 70 ×).

for the marginal rods. The gingival wall is prepared in the same way, inclined gingivally about 6 centigrades from the horizontal plane, and the cavosurface angle bevelled. Fig. 75 shows the walls prepared.

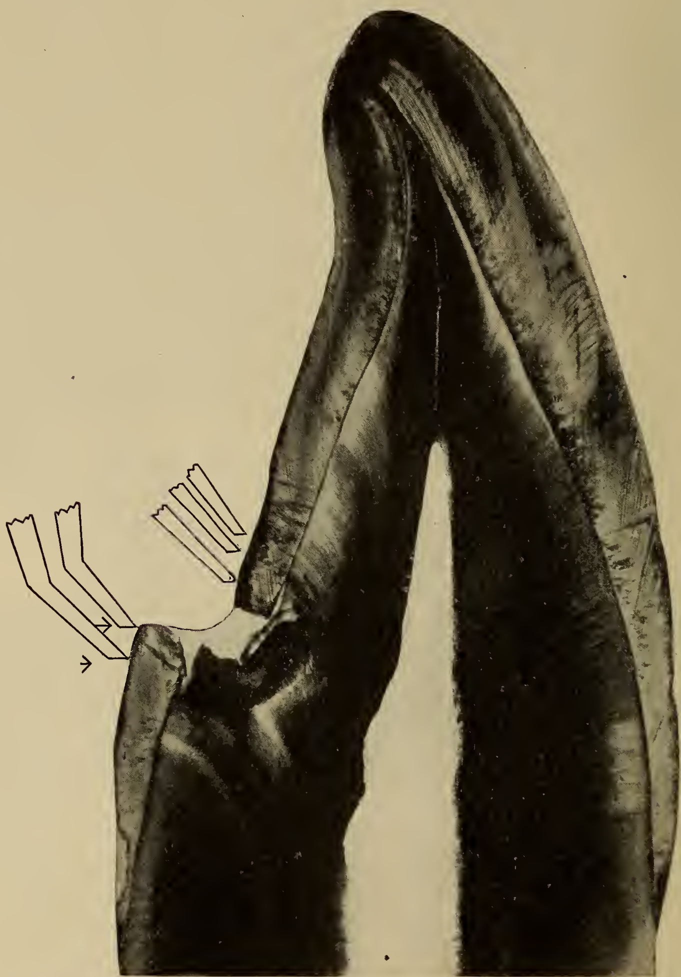


Fig. 79.—A cavity in the lingual pit of a lateral incisor. The position of the chisel in opening the cavity.

Fig. 76 is a similar section from a molar. After chopping away the occlusal wall until the cavity has been extended to the point of greatest convexity of the surface, the wall is seen to be in the

Fig. 80.—The preparation of the gingival wall of the cavity shown in Fig. 79.

Fig. 81.—The preparation of the cavity shown in Fig. 79.

condition shown in Fig. 77. Near the surface the enamel has broken across the rods and near the dento-enamel junction the same thing has happened, but in the rest of the distance the cleavage has followed the enamel rod direction. The inclination of the wall is increased by planing until this roughness has been removed, and then the cavosurface angle is bevelled to support the marginal rods, and preparation is complete, as shown in Fig. 78.

Fig. 79 shows a cavity in the lingual pit of a superior lateral incisor. Caries has undermined the enamel to a considerable extent, and the cavity will have to be larger than would otherwise have been necessary. Placing the chisel close to the occlusal margin, as indicated, the enamel is chipped away in that direction and around the circumference. On the lingual wall the chisel may be reversed and used with a pulling motion, like a hoe. In this way the undermined enamel is chipped away and the tip of the marginal ridge removed. The wall is then planed into the horizontal plane and the cavosurface angle bevelled. Fig. 80 shows the structure of the gingival wall, and Fig. 81 the relation to the crown.

CHAPTER IX.

STRUCTURAL DEFECTS IN THE ENAMEL.

The formation of enamel begins at the dento-enamel junction, and the tissue is laid down from within outward, so that the enamel in contact with the dentin is formed first and the surface of the crown last. Enamel formation begins at several points for each crown, the exact number and position of which has been the subject of much investigation. When enamel formation begins, these points are close together, but they are carried farther apart by the growth of the dental papilla, and are not united for some time. The separate enamel caplets unite first at the dento-enamel junction, and as the formation of the thickness of the enamel progresses at these lines of union, there is always more or less disturbance in structure. Even where the union seems perfect, sections will show more or less disturbance of enamel-rod direction, arrangement of the rods, and relation to the cementing substance.

Every operator and student of dental anatomy is familiar with the developmental lines. On the occlusal surfaces they are usually marked by well-defined grooves, but upon the axial surfaces the grooves may be very slight, scarcely more than slight depressions of the surface, and consequently they are not thought of. It will be found, however, that on these lines there is less perfect enamel structure, and consequently the tissue is not as strong, and these lines must be avoided in the preparation of enamel walls. The cause of disturbance of structure will be better understood after study of the development of the tooth germ and the formation of enamel in the chapter on Dental Embryology, but some details of the cause should be touched upon here. The study of the diagrams of the growth of the tooth crown will illustrate the conditions (see Chapter XXVI, Fig. 278), and shows a buccolingual section through the tooth germ of a bicuspid just before the formation of the dentin and the enamel begins. The odontoblasts (dentin-forming cells) and the ameloblasts (enamel-forming cells) are in contact at what will be the dento-enamel junction. The odontoblasts form dentin on their outer surface, beginning at the tip of the dentin cusp, and progress from without inward and extend down the slopes of the cusps. The ameloblasts form enamel on their inner surface and progress from within outward and down

Fig. 82

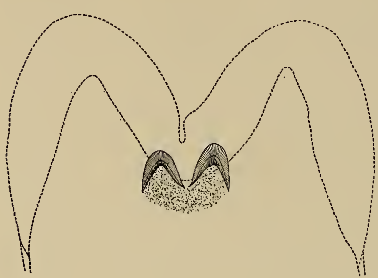


Fig. 83

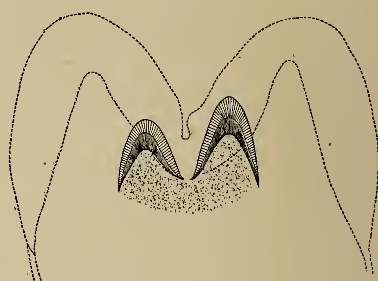


Fig. 84

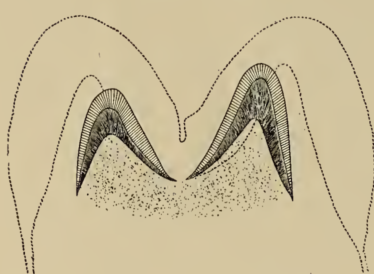


Fig. 85

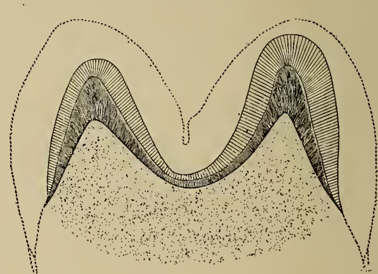


Fig. 86

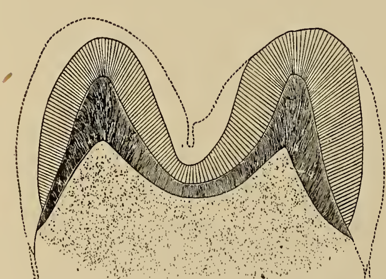
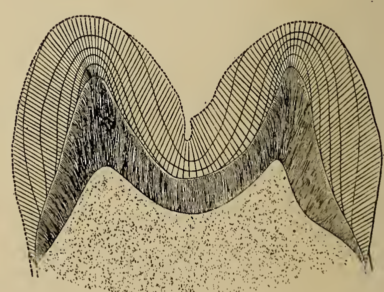


Fig. 87



Figs. 82 to 87.—Diagrams showing the growth of the crown of a bicuspid.

the slopes of the cusps. In this way little caplets of dentin covered by enamel are formed over the horns of the dental papilla; the caps are, of course, thickest where formation has been going on longest. While these caps are forming, the dental papilla is increasing in size, and so they are carried farther and farther apart (Figs.

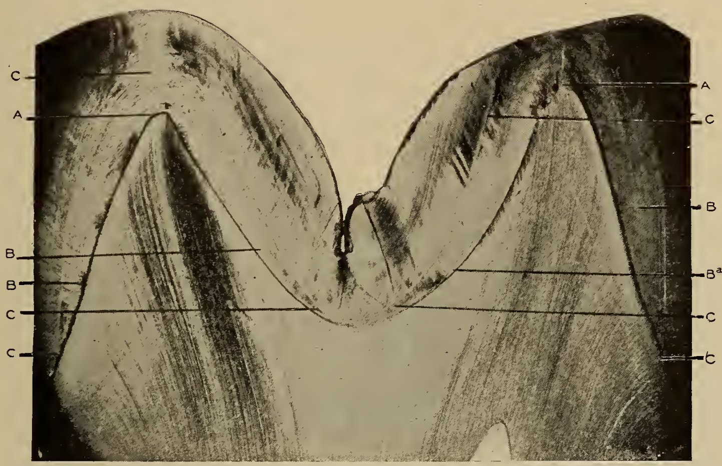


FIG. 88.—The section from which Figs. 82 to 87 were drawn: *A*, tip of dentin cusp; *B*, lines showing little caps of enamel formed before calcifications from separate centres united; *C*, lines showing amount of enamel formed when calcifications united.

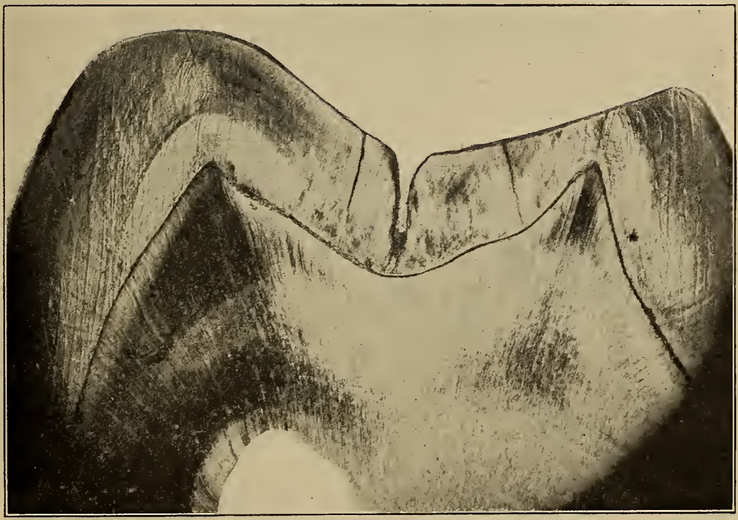


FIG. 89.—Occlusal defects from an old tooth

82 to 87). As soon as the calcifications reach each other at the dento-enamel junction and unite, the increase in the diameter of

the dental papilla ceases. The layer of ameloblasts, which are tall columnar cells, now cover the surface of the enamel and receive

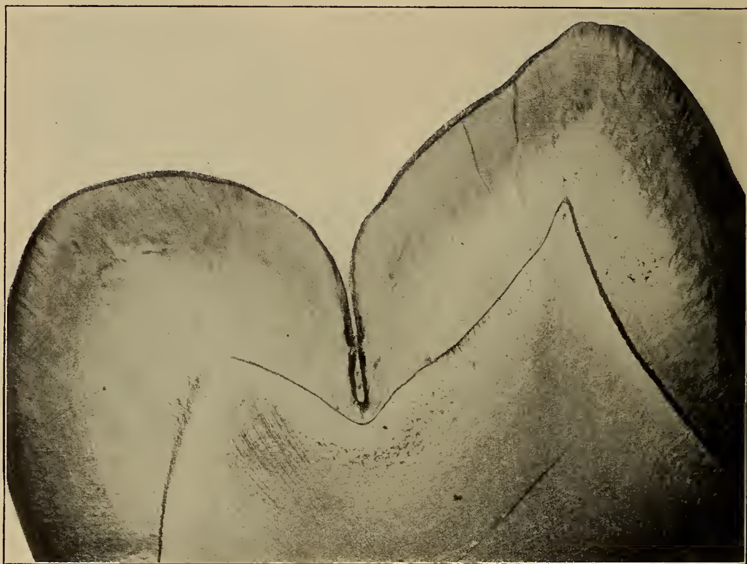


Fig. 90.—A deep, open groove.

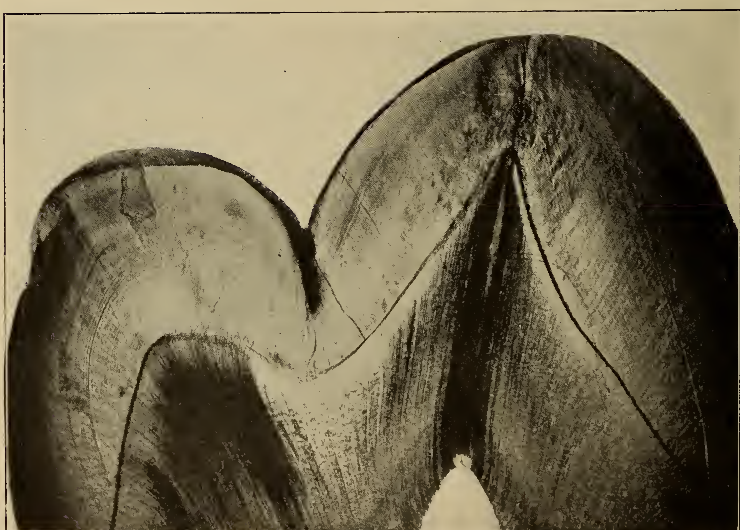


Fig. 91.—A shallow groove.

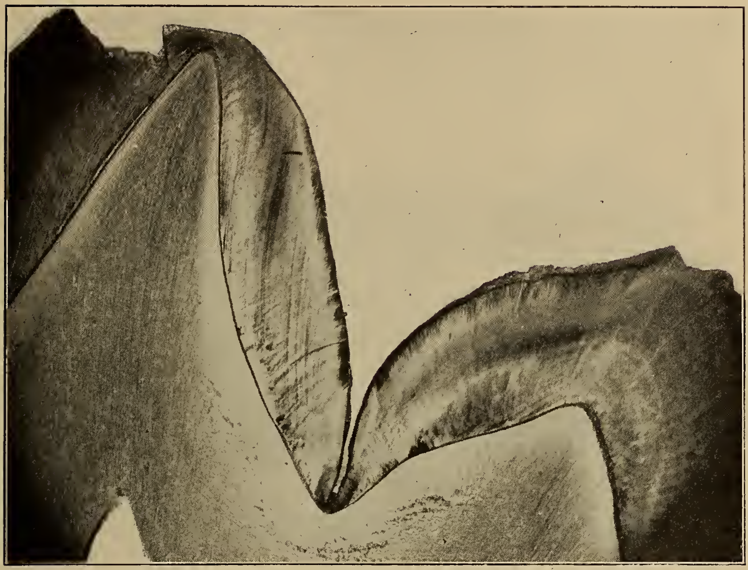


FIG. 92.—A very deep groove, showing the effect of caries at the bottom.

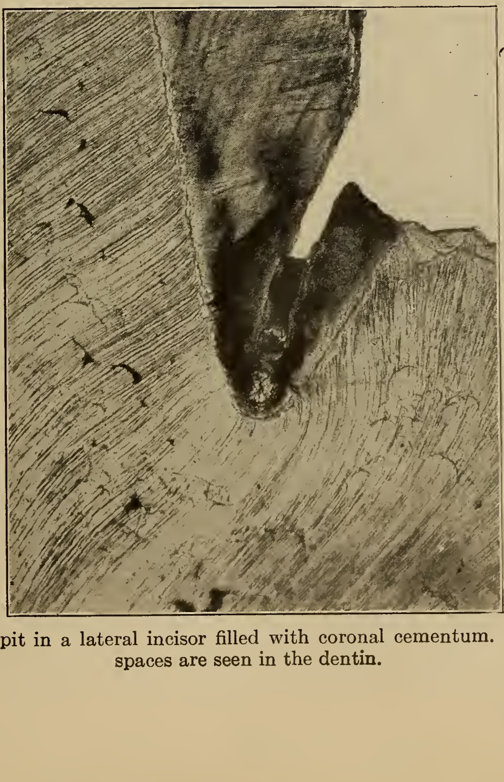


FIG. 93.—The pit in a lateral incisor filled with coronal cementum. Interglobular spaces are seen in the dentin.

their nourishment and the materials for the formation of enamel from the blood supply through the stratum intermedium. As the blood supply comes from above, it is evident that the cells high up along the slopes of the cusps will receive most, while those

Fig. 94

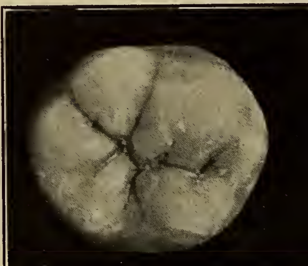


Fig. 95

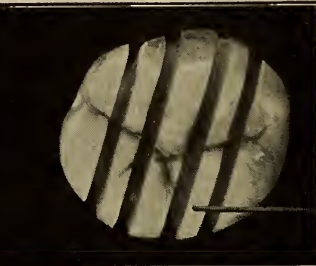


Fig. 94.—Occlusal surface of the lower third molar, showing the grooves.
Fig. 95.—The same tooth sliced for sectioning: *1*, the piece from which the section shown in Figs. 96 and 97 was ground.

at the bottom of the groove get what is left. The formation is therefore more rapid along the slopes and less rapid at the point of union. As growth continues, this difference in supply increases, and accordingly formation at the bottom of the groove is first

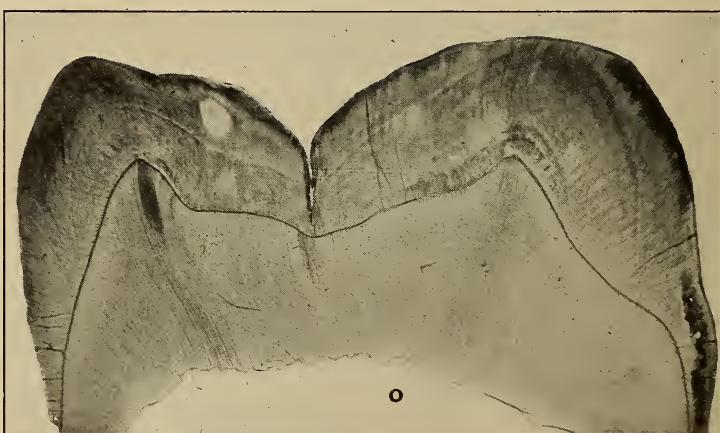


Fig. 96.—The section ground from *1*, Fig. 95, showing the depth of the fissure.

slowed and finally stopped, and the result is a defect. The taller the cusps the greater will be the interference and the deeper the defective groove. In studying sections (Figs. 88 to 92) it is very noticeable that teeth with long pointed cusps have more open grooves, and the defect often extends almost or quite to the dento-enamel junction.

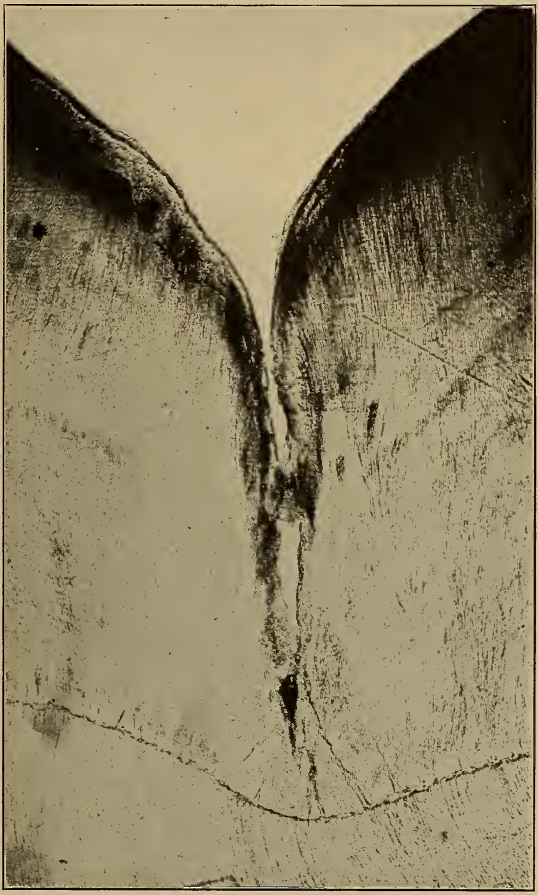


Fig. 97.—Higher magnification of the fissure shown in Fig. 96. (About 60 ×)

The bands of Retzius, which are the incremental lines of the enamel about these grooves, should be studied. It will be seen that they always dip down around the groove, and that more enamel has been formed between one band (Figs. 98 and 99) and the next on the slope of the cusps than at the bottom of the groove. In teeth with very flat, low cusps the closure of the grooves may be very perfect, leaving only a slight depression (Fig. 91).

The importance of these defects as positions of beginning caries cannot be overestimated, as they furnish ideal conditions in areas that would otherwise be immune, and they are the positions in which the attacks of caries are first manifested. These occlusal grooves appear in great variety. Some are simply shallow, open grooves, in which the surface of the enamel is perfect (Fig. 88); some are very deep and entirely empty (Figs. 89, 90, and 92); others are apparently filled with a granular, more or less structureless calcified material which appears to have been deposited in the groove after the enamel was completed (Figs. 93, 98, and 99). This is probably of the nature of cementum. It was formed after

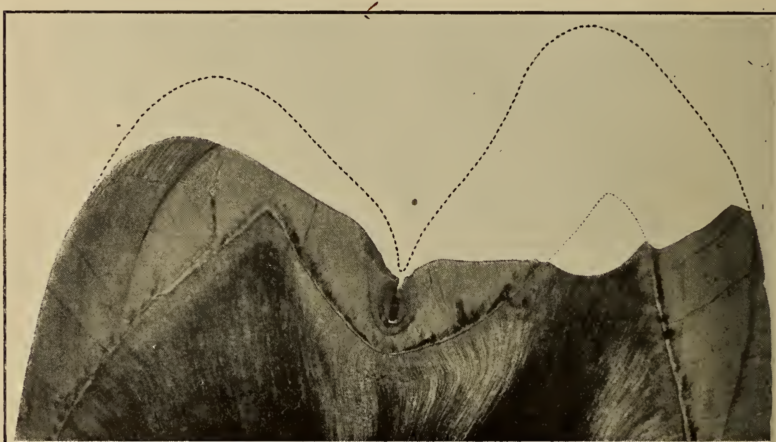


Fig. 98.—An occlusal defect in a worn tooth. The fissure is filled with coronal cementum.

the enamel was completed, but while the tooth was enclosed in its follicle in the crypt in the bone. It is to be compared with the coronal cementum that is characteristic of the complex grinding teeth of the ungulates and other herbivorous animals. A study of these defects furnishes the basis for the operative rule that "all grooves must be cut out to the point where the margin will be on a smooth surface." For if they are not, a defect will be left at the margin of the cavity which offers ideal conditions for the beginning of a new decay. When caries begins in such a defect at the margin of a filling, it progresses at the bottom of the defect until the dento-enamel junction is reached, and then extends in the dentin and may destroy the entire crown without showing upon the surface (page 50). The extent of these defects is much greater than would be supposed from the observation of the teeth in the mouth. Fig. 94 shows the occlusal view of a lower third molar,

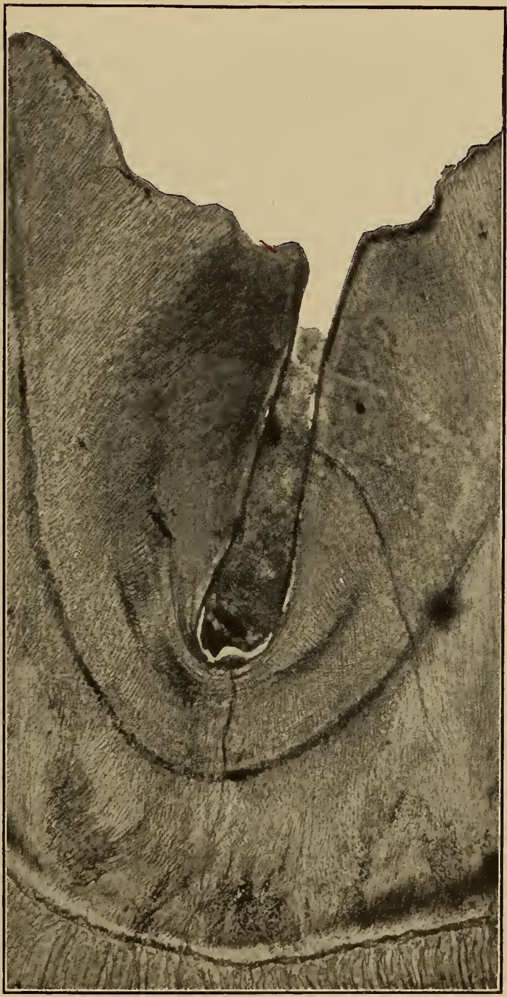


Fig. 99.—Higher magnification of Fig. 98. The fissure filled with granular calcified material. Notice the direction of the bands of Retzius around the fissure.

extracted because of disease of the peridental membrane, from a man aged about forty years. Examining these grooves with a fine-pointed explorer, it would not stick any place. No operator would think of cutting them out and filling them. The crown was sawed through from buccal to lingual, as shown in Fig. 95, and the piece marked *1* is shown in Figs. 96 and 97. The grooves are open

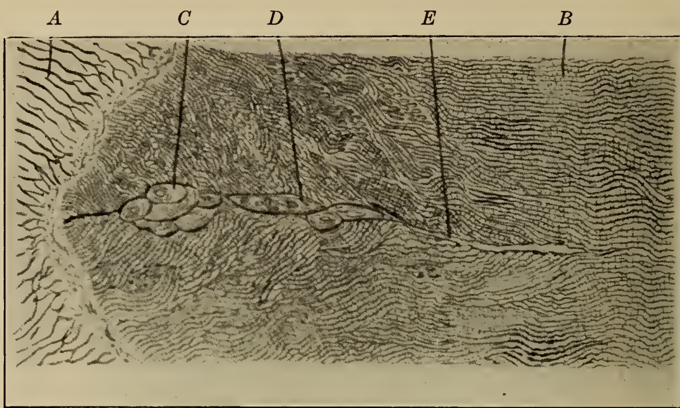


Fig. 100.—Structural defects in developmental grooves on axial surfaces. (Black.)

two-thirds of the distance to the dento-enamel junction, and show slight action of caries. Suppose caries had started in the central pit, and a small round filling had been made, open defects would

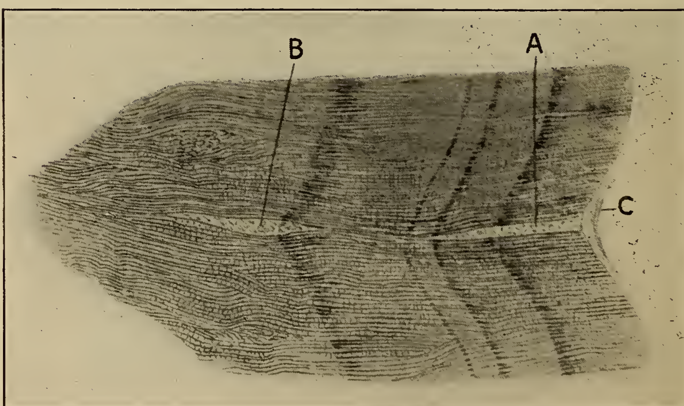


Fig. 101.—Structural defects in developmental grooves on axial surfaces. (Black.)

be left at the margin where every groove radiated from the central cavity, and these would be just as liable to recurrent decay as they were originally, and, if caries occurred, it would progress at the depth of the groove, reach the dento-enamel junction, and progress in the dentin, until the occlusal enamel was so undermined that it would break in under the force of mastication. On the other hand, if the grooves are cut out to a point where the cavity margin will be on a smooth surface, there is no possibility of recurrent caries if the filling material is properly inserted. This one illustration, which might be duplicated a thousand times, therefore is the rational basis for the rule, "All grooves must be cut out to their ends."

Caries does not occur in all open grooves. Fig. 90 shows an open groove in a section from a tooth in which the wear indicates

Fig. 102.—Defects on the axial surface in the enamel.

that it was not from a young person, but most of the grooves that escape are not open, but more or less entirely filled with structureless calcified matter or coronal cementum. Figs. 93, 98, and 99 are very good illustrations of this class of grooves.

The condition in pits from which grooves extend, as the lingual pits of incisors and the buccal pits of molars, show the same condition as the grooves, except that the defect is both broader and deeper. But pits that are sometimes found on the tips of cusps and on smooth surfaces show an entirely different structural condition, and are pathologic in character.

In places where the union of the enamel plates seems perfect, as, for instance, on the labial surface of the incisors or the buccal surface of the bicuspids, and the line of union is marked only by a slight depression of the surface, the section will show disturbance of structure. Fig. 101, a drawing made by Dr. Black a good many years ago, shows such a position. At the surface the rods and their arrangement seem very perfect, but from a point about one-third the distance to the dento-enamel junction there are no rods at all, but apparently a number of calcospherites in a granular

Fig. 103.—A section through such a defect as that shown in Fig. 102. (About 80 ×)

calcific substance. In Fig. 101, another of Dr. Black's illustrations, the rods are very irregular, and are separated by large areas of structureless calcified material. Grooves are often found in unusual or atypical positions. Fig. 102 shows a groove running over the mesial marginal ridge and down on the mesial surface. Fig. 103 shows a section through such a defect. Notice the folding of the enamel into the dentin and the disturbance of the rods about the groove and between its base and the dentin.

CHAPTER X.

SPECIAL AREAS OF WEAKNESS FOR ENAMEL MARGINS.

THERE are certain positions which in the perfect crown are areas of great strength, but which, because of the peculiar structure of the tissue in these places, become areas of weakness when cavity

FIG. 104.—Buccolingual section of upper bicuspid. Enamel is broken from grinding. *A* to *B*, area of weakness for enamel margin. (About 20 ×)

margins are made in them. The treatment of beginning caries would lead to no failures in these positions, for cavity margins would never be extended into them, except in the treatment of

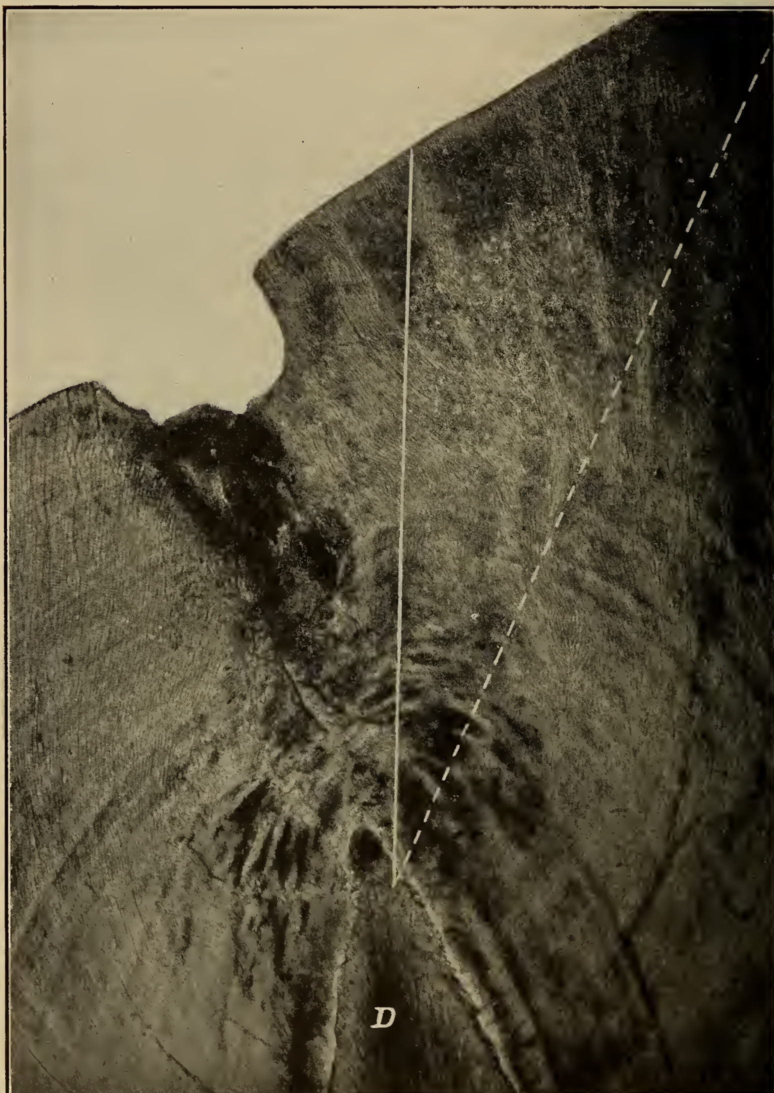


FIG. 105.—Enamel over tip of dentin cusp: *D*, dentin cusp. (About 80 ×). From same section as Fig. 104.

burrowing caries and neglected cases. The extension of caries at the dento-enamel junction often requires the extension of the margin into the area of danger. In considering these areas and in the preparation of cavities, as well as the areas of imperfect structure considered in Chapter IX, it is important to place as much emphasis on the necessity of **not extending cavity margins into the areas of weakness**, as on cutting away the dangerous area and leaving the margin in a safe position, when the area cannot be avoided.

In considering the relation of the enamel and dentin, and in studying the arrangement of the enamel-rod direction in the "architecture" of the tooth crown, it has been pointed out that the dentin cusps and the dentinal marginal ridges are not directly under the corresponding points on the surface of the enamel, but are nearer to the axis of the tooth. The areas on the surface of the enamel, from the point directly over the tip of the dentin cusp or ridge to the tip of the enamel cusps or ridges, become areas of weakness when a cavity is extended into them.

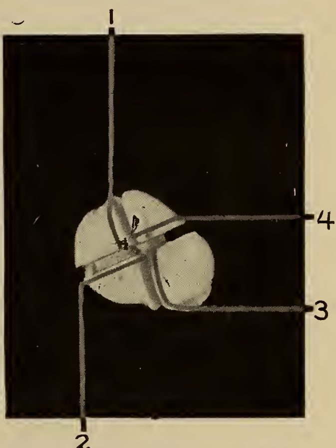


FIG. 106.—A bicuspid cut for sectioning. Sections were ground from the positions marked by the lines *1*, *2*, *3*, *4*, and *4* is also shown in Figs. 107, and 108.

Fig. 104 is a photomicrograph of a buccolingual section of a superior bicuspid, and Fig. 105 is a higher magnification of the same, made to illustrate the condition. It will be seen that if decay has extended at the dento-enamel junction to the tip of the dentin cusp, and the enamel walls were left in the axial plane, the rods which form the surface of the enamel from the margin of the cavity to the tip of the cusp "are not supported by dentin," and would be likely to be broken and fall away, leaving a defect at the margin of the filling. If decay beginning in the groove or pit has extended only to point *C*, Fig. 104, the wall may be trimmed in the axial plane and an ideal wall produced; but if it has reached point *D*, Fig. 104, it must be inclined buccally so as to remove the tip of the cusp, as indicated in the dotted line, and the cusp restored by the filling material. The region of the surface indicated by *A–B*, while an area of strength in the perfect tissue, becomes a position of weakness when cavity margins are extended into it. A careful

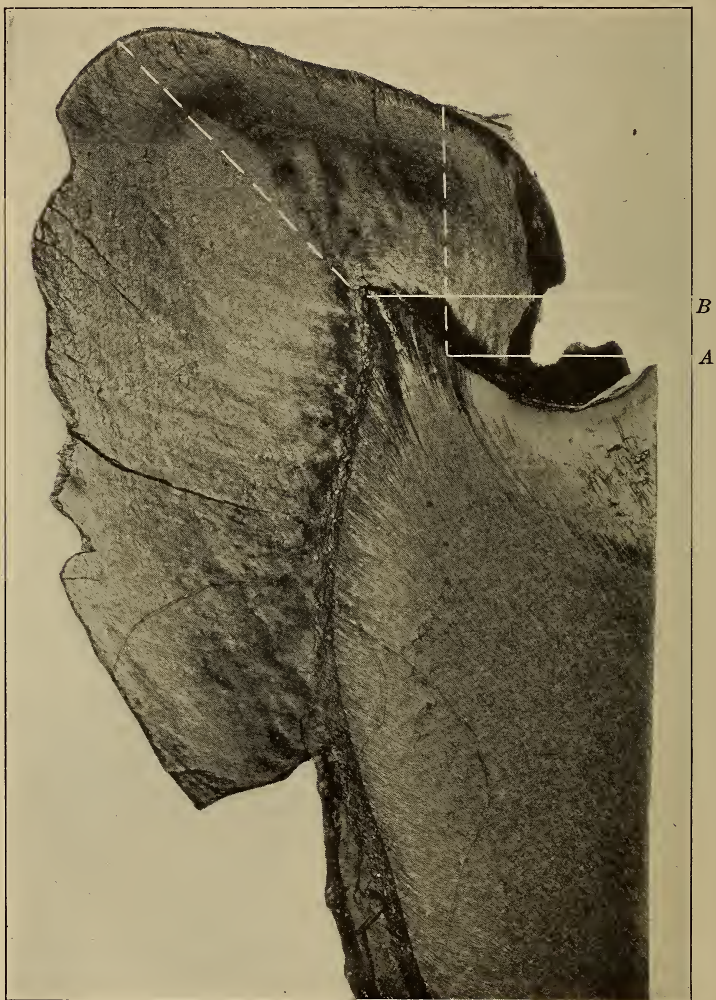


Fig. 107.—Section ground from Fig. 106, through mesial part and marginal ridge. If caries has extended at the dento-enamel junction to *A*, the wall may be in the axial plane; if it has reached *B*, the wall must be inclined as indicated by the dotted line. (About 30 ×)

observer will find many failures that are the result of bad enamel-wall preparation in these areas. The same conditions exist in the region of the marginal ridges. Figs. 107 and 108 show the mesial marginal ridge of a superior bicuspid. If this is filled before the destruction of dentin has extended beyond the point *A*, the mesial wall may be cut in the axial plane as indicated; but if it has reached the tip of the dentin ridge at point *B*, it must be inclined mesially, so as to reach the tip of the enamel ridge. Figs. 109 and 110 show

Fig. 108.—A higher magnification of Fig. 107, showing enamel-rod directions in the region of the marginal ridge.

the distal marginal ridge in a second molar. Notice the inclination of the rods from the tip of the dentin ridge. If decay has reached this point the wall must be inclined distally, so as to reach the rod direction, or a frail margin will be left and one which will not sustain the force of mastication. Neglected caries in the lingual pits of incisors often present the same conditions as found in the marginal ridges of the occlusal surface of molars and bicuspids. The same conditions are also often encountered in the preparation of simple cavities in the mesial or distal surfaces of incisors, when caries has followed the dento-enamel junction toward the lingual. Fig. 111 shows a superior central incisor from which sections were cut as indicated. Suppose caries to have begun in the region of the contact point and to have extended to the point *a*. If the lingual enamel wall were prepared at the line *A*, Fig. 112, a very frail wall would result. Force coming upon this wall from the lingual by the occlusion of the lower incisors, would be likely to break out or crack a triangular piece of enamel, and the filling would fail along the lingual wall. If, however, the wall be laid in the line at *B*, a strong wall is produced, against which gold can be properly condensed without danger, and which will withstand the force of occlusion.

Fig. 109.—An upper molar, showing the position of the section shown in Fig. 110.

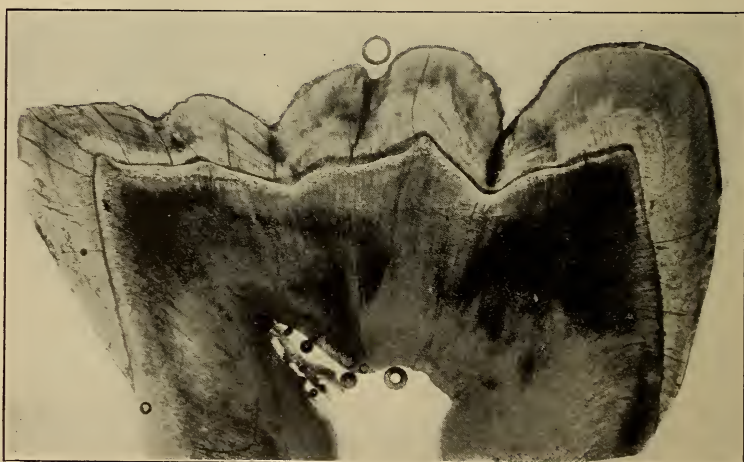


Fig. 110.—The section ground from Fig. 109.

Dentists are often tempted to prepare simple cavities in the mesial surfaces of first and second bicuspids and occasionally in the molars. If this is ever done, it must be with the full knowledge both of the liability of recurrence of caries and the structure of the enamel, for experience shows that such operations usually fail, either by recurrence of caries at the buccogingival or linguogingival angles, or by the breaking out of the enamel of the marginal ridge. Fig. 115 shows the mesial surface of a superior bicuspid. There was a white spot on the contact point, but no actual cavity, as the enamel rods had not fallen out. A section was ground through this point, and Fig. 116 shows a photomicrograph of it. The enamel rods have fallen out of the disintegrated area, and the decalcification in the dentin is shown. If this had been treated as a simple cavity the occlusal wall would have required an inclination of 18 centigrades occlusally from the horizontal plane to reach the enamel-rod direction. There is very little support offered by the dentin for the enamel of the marginal ridge, and the portion over to the occlusal groove would be likely to be broken off by the force of mastication. The conditions of the occlusal wall are better shown in Fig. 117.

Fig. 111.—A superior central incisor, showing the position of sections in Figs. 112, 113 and 114.

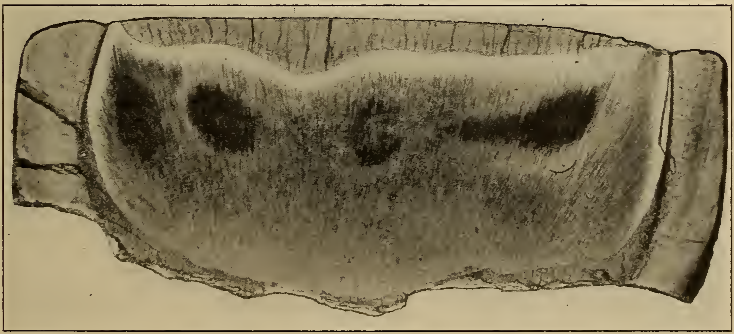


Fig. 112.—Section 1, Fig. 111, showing the enamel worn from the marginal ridges.

Any number of illustrations of these conditions might be made, but the subject may be summed up by saying: The surface of the enamel from the point directly over the dentin cusp or ridge to the tip of the enamel cusp or ridge, which is an area of great strength in the perfect crown, is a region of weakness for an enamel wall. It is fully as important not to extend into this area unnecessarily

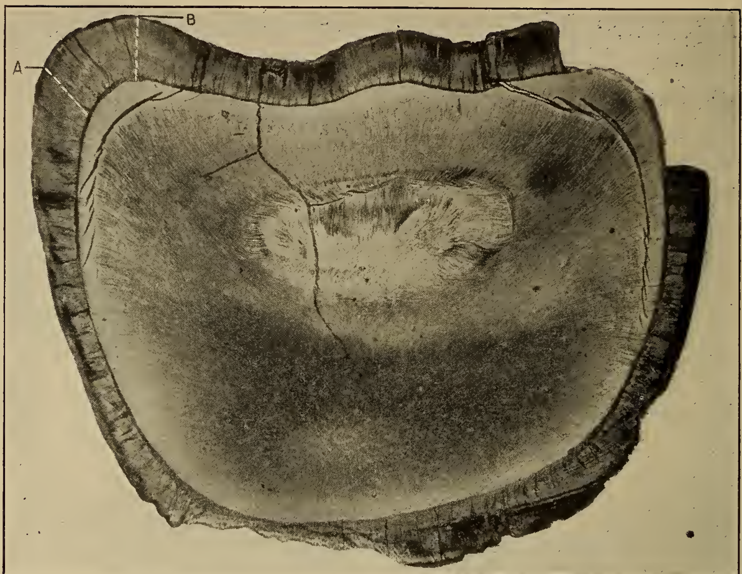


Fig. 113.—Section 2, Fig. 111, showing position of weak and strong lingual walls.

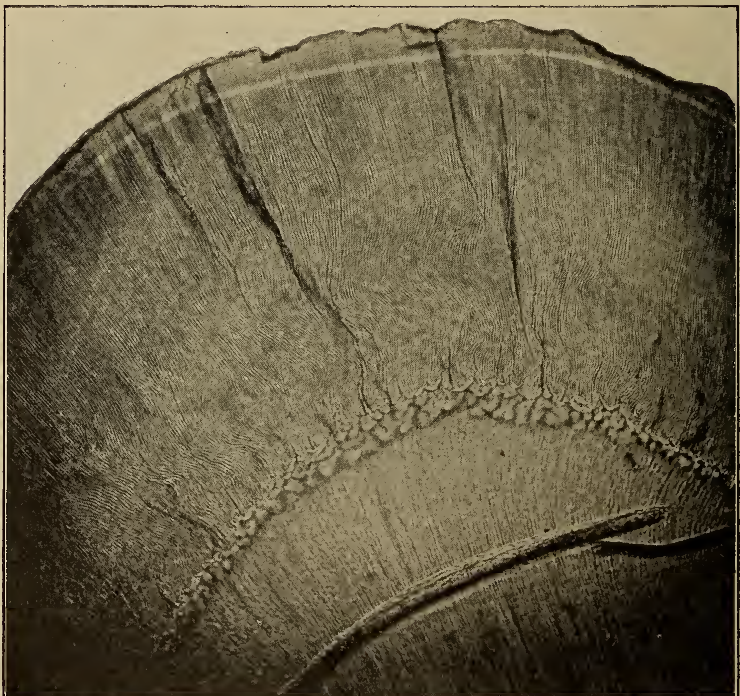


Fig. 114.—A higher magnification of the mesial marginal ridge, shown in Fig. 113. (About 60 ×)

as to form the wall proper when caries has extended so as to involve it. When caries of a smooth surface approaches a marginal ridge which receives the force of occlusion, the wall must

Fig. 115.—Occlusal and mesial views of a superior bicuspid, showing position of section. A beginning caries could be seen on the surface, but it does not show well in the picture. The section from the buccal piece is shown in the following illustrations.

Fig. 116.—The section ground from the buccal piece, Fig. 115.

be extended so that the enamel receives full support from sound dentin.

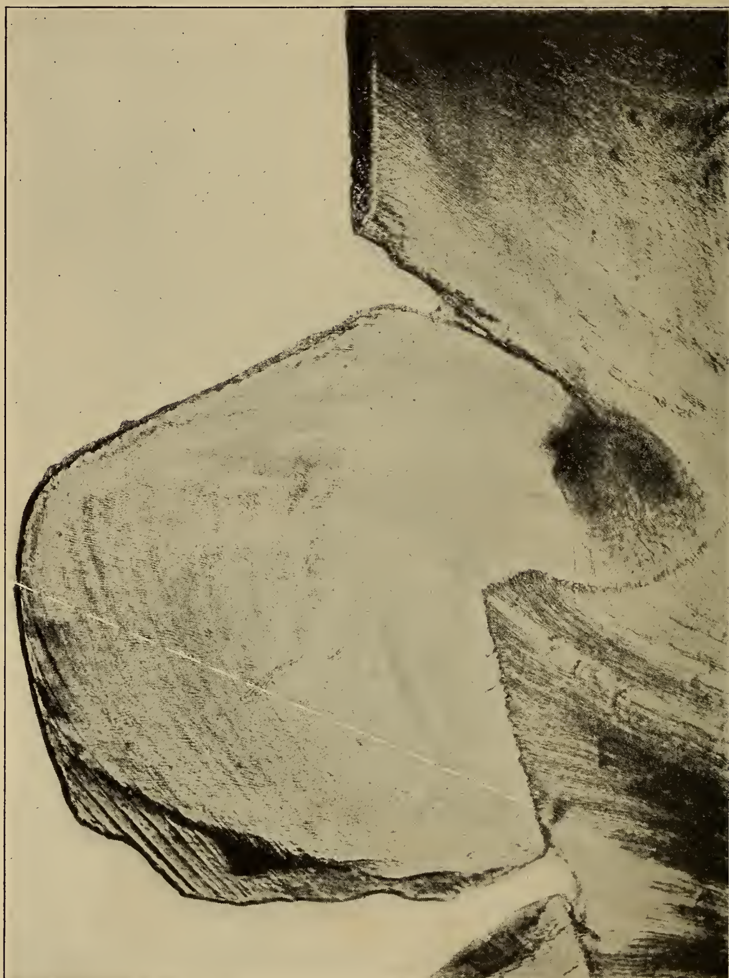


Fig. 117.—The enamel over the mesial marginal ridge to the oblique groove, showing a region of weakness for the occlusal wall of a simple proximal cavity.

CHAPTER XI.

THE DENTIN.

The dentin may be defined as a connective tissue whose intercellular substance is calcified. It is apparently homogeneous in structure, but penetrated by minute canals, which contain protoplasmic projections from cells lying within a cavity enclosed by the tissue.

The Function of the Dentin.—The dentin makes up the mass of the tooth, giving to it its general form, each cusp and root being indicated in it. It gives to the tooth its elastic strength, and the enamel, being hard and very resistant to abrasion but extremely brittle, is dependent upon the elastic support of the dentin. This has been elaborated to a considerable extent in the chapter on the Dental Tissues. The fact that the dentin gives the strength to the tooth should never be lost sight of in operating, and sound dentin should never be sacrificed unnecessarily in the preparation of cavities.

Structural Elements of the Dentin.—The structural elements of the dentin may be stated as:

1. The dentin matrix.
2. The sheaths of Newman and the dentinal tubules.
3. The contents of the dentinal tubules or the dentinal fibrils.

While these are the elements of which the tissue is composed, there are other characteristic appearances found in the dentin, caused by special conditions or arrangement of these elements which must be studied. These are the granular layer of Tomes, the interglobular spaces, the lines of Schreger, and secondary dentin.

Origin of the Tissue (Histogenesis).—The dentin, like all of the other calcified tissues except the enamel, is a connective tissue, and is formed by the dental papilla, which is a conical papilla of connective tissue rich in bloodvessels and covered on its surface by the layer of dentin-forming cells, the odontoblasts. The dentin is formed from without inward, leaving the remains of the dental papilla in the cavity of the formed dentin as the dental pulp. Before the tooth is erupted, and up to the time that the full length of the root is formed, a characteristic thickness of dentin is formed, which is called the *primary dentin.* After this time dentin is formed by the pulp only intermittently, in response to irritations and trophic impulses, producing *secondary dentin.* Secondary dentin is always more irregular in the arrangement of the tubules, and more imperfect in structure than the primary dentin. The boundary line between two periods of dentin formation can always be picked out by changes in the direction or character of the dentinal tubules.

The Dentin Matrix.—The dentin matrix is a solid, apparently homogeneous, and very elastic substance, through which the dentinal tubules extend. It is translucent in appearance and slightly yellowish in color. In broken or split sections to the unaided eye it has a yellowish color by reflected light, and a characteristic luster due to the refraction of light by the tubules. In ground sections, by transmitted light, under the microscope, it is very translucent and shows no indication of structure.

The matrix consists of an organic basis of ultimately fibrous character, yielding gelatin on boiling, with which the inorganic salts are chemically combined. The relation of organic and inorganic matter in the dentin matrix is similar to the condition in the bone matrix and that of all calcified connective tissues. Apparently the organic basis is first formed, and then the inorganic salts are combined with it in a weak chemical union. If the dentin is treated with dilute acid, the inorganic matter is dissolved and the organic basis is left retaining the form of the tissue. If the organic matter is burned out, it leaves the inorganic matter in the characteristic form.

Von Bibra gives the following analysis of perfectly dry dentin:

Organic matter	27.61
Fat	0.40
Calcium phosphate and fluoride	66.72
Calcium carbonate	3.36
Magnesium phosphate	1.08
Other salts	0.83

Mr. Charles Tomes pointed out that such analyses as this failed to take account of about 8 per cent. of water which is held as water of combination, and which is driven off at about red heat.

It is evident that the organic matter in the dentin is of two kinds —the organic basis of the matrix, which is of gelatin-yielding character, and the protoplasmic contents of the dentinal tubules. Variations, therefore, in the proportion of organic and inorganic matter in the dentin might be caused by differences in the proportions of organic and inorganic constituents of the matrix, or by variations in the size of the tubules and the amount of material contained in them.

If dentin changes in its degree of calcification with age, this might be brought about by the reduction in the size of the tubules, or by the adding of inorganic constituents to the matrix.

The amount of material contained in the dentinal tubules is much greater than is generally realized. If 2μ is considered the average diameter of the dentinal tubules, and they are separated by an average of 8μ of dentin matrix. Some idea of the relative volume of the dentin matrix and the contents of the tubules can be obtained, but this is greatly increased by the very numerous side branches which connect the neighboring tubules. This matter can be visualized by taking a lump of soft clay and boring it full of holes, making the holes two inches in diameter, and separated by eight inches of clay.

The ultimately fibrous character of the dentin matrix can be made out only in various stages of decalcification and decomposition. In the original condition no trace of the fibrous character can be seen. By maceration with acids and alkalies the intertubular material assumes a fibrous appearance, as if bundles of white connective-tissue fibers had been fused together. There is apparently no definite arrangement of these fibers and there is no indication of the arrangement of the substance in layers.

The Sheaths of Newman.—There has been much discussion as to the character of these structures, which were first discovered in 1863 by Newman. Some investigators have denied their existence entirely, explaining the appearance in some other way. These structures are in no sense a sheath surrounding the dentinal fibril and lying in the dentinal tubule, but are that portion of the matrix which forms the immediate wall of the tubule. That this material differs from that which occupies the rest of the space between the tubules is certain, and is shown by the examination of ground sections, the action of stains upon ground sections, and the action of the matrix when boiled with strong acids and alkalies. In Fig. 118, a photograph of a ground section, there is evidently a difference in the refracting index of the portion of the matrix immediately surrounding the tubules. Apparently the sheaths of Newman are composed of a material similar to that forming elastic connective-tissue fibers, and known as elastin. This substance is very resistant to the action of acids and alkalies. After the remainder of the intertubular material has been destroyed by boiling with strong acid, the sheaths remain like hollow elastic fibers, having the appearance of pipe-stems, which resist long-continued action of the boiling acid. Some authors have suggested that the great elasticity of the dentin was largely due to the presence of this substance.[1]

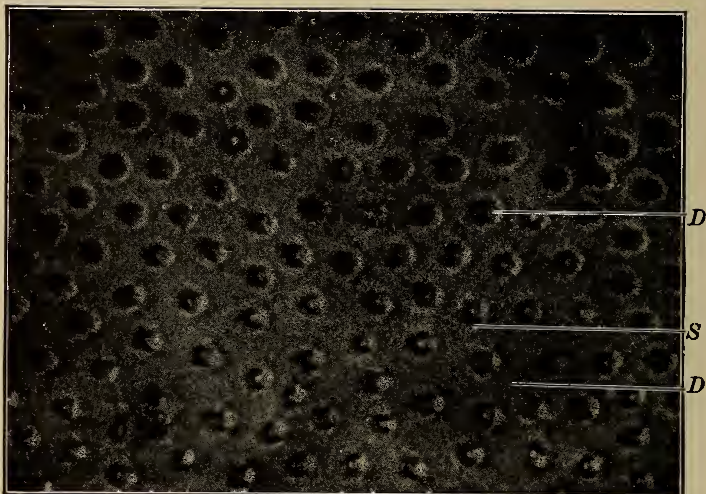


Fig. 118.—Dentin showing tubules in cross-section: *Dt*, dentinal tubules; *D*, dentin matrix; *S*, shadow of sheaths of Newman. (About 1150 ×)

The Dentinal Tubules.—The dentin matrix is penetrated everywhere by minute branching tubules, which radiate from the central cavity or pulp chamber and extend to the outer surface of the dentin at the dento-enamel junction or the dento-cemental junction, where they end blindly or in irregular enlargements. These tubules are from 1.1 to 3 microns in diameter. One hundred measurements[2] made at random from ground sections gave the extreme measurement: 3, largest; 1.5, smallest; and average, 2.95. Fifty measurements from one longitudinal section of tubules at their pulpal extremity gave an average of 2.6; largest, 3; smallest, 1.5; and 50 measurements at the dento-enamel junction of the same section

[1] Hawazawa, Tokyo: A Study of the Minute Structure of Human Dentin, Trans. Panama Pacific Dental Congress, 1915, p. 80, and Dental Cosmos, February and March, 1917, vol. ix.

[2] Kölliker gives 5 microns, also Schäfer; Owen, 2.5 microns.

gave the following: Average, 1.2; largest, 1.5; smallest, 0.75. These measurements were made with an eye-piece micrometer, using $\frac{1}{12}$ oil-immersion objective and No. 3 ocular.

At the present time there is a fertile field for investigation offered in regard to the size of dentinal tubules. Many statements have been made that have not been supported by tabulated measurements, and no definite statement can be made as to the variations and size of the dentinal tubules in different teeth, the teeth of different animals, or in the human teeth at different ages.

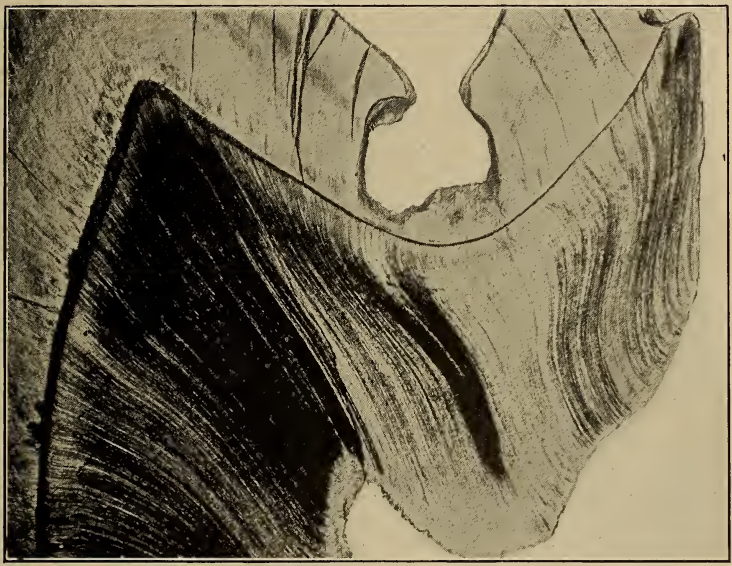


Fig. 119.—A section showing the primary curvatures of the dentinal tubules in the crown portion. (About 20 ×)

Direction of Tubules in Crown Portion.—In the crown portion and the gingival portion of the dentin the tubules pass from the pulp chamber to the dento-enamel junction, or the dento-cemental junction, in sweeping curves, which were called by Tomes the primary curvatures. These have been described as *f*- or *S*-shaped (Fig. 119). The tubule tends to enter the pulp chamber at right angles to the surface, and to end at the dento-enamel junction at right angles to that surface. In the dentin forming the axial walls of the pulp chamber the tubules make two bends in passing from the pulp chamber to the surface of the dentin. In the first the convexity is directed apically, in the second it is directed occlusally.

The outer extremity of the tubule is therefore considerably farther to the occlusal than the point at which it opens into the pulp cham-

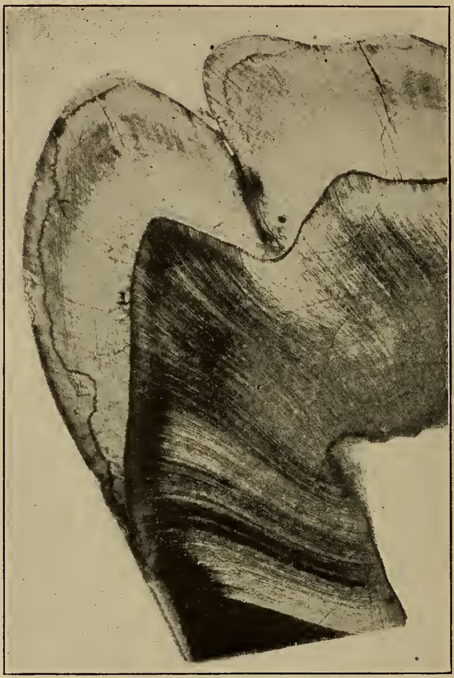


FIG. 120.—A section showing the primary curvature of the dentinal tubules in the gingival portion. (About 20 ×)

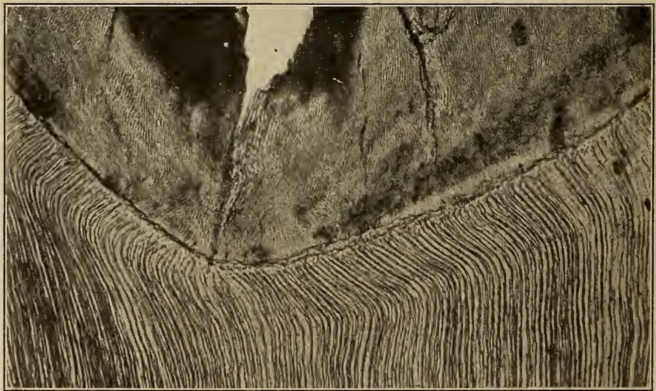


FIG. 121.—A section showing compound curves near the dento-enamel junction. (About 80 ×)

ber (Fig. 120). The outer part of this double curve is often complex instead of simple (Fig. 121). The course of the dentinal tubules is not a direct one, but that of an open spiral. This may easily be demonstrated by changing the focus up and down in examining sections cut at right angles to the direction of the tubules. When examined in longitudinal sections this spiral course gives to the

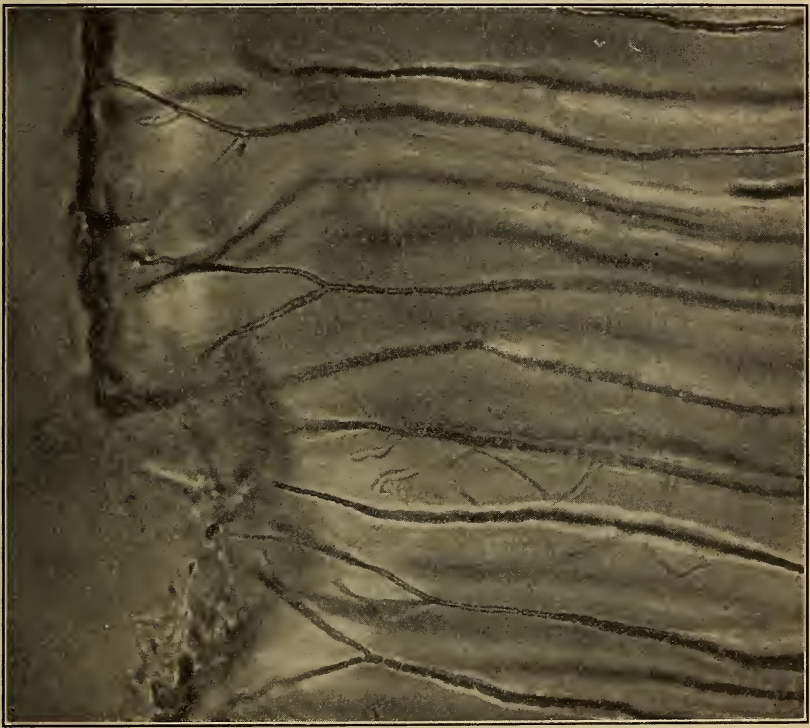


FIG. 122.—Dentin at dento-enamel junction, showing tubules cut longitudinally. (About 760 ×)

tubule the appearance of having little wavy curves throughout its length. These have often been called the secondary curvatures. Each wave represents a turn in the spiral. As many as two hundred have been counted in the length of a single tubule, or about one hundred in a millimeter of length.

The dentinal tubules give off minute lateral branches, which extend from one tubule to another. These are very minute, and in the crown portion of the dentin are not at all conspicuous, but in the region of the dento-enamel junction the tubules branch

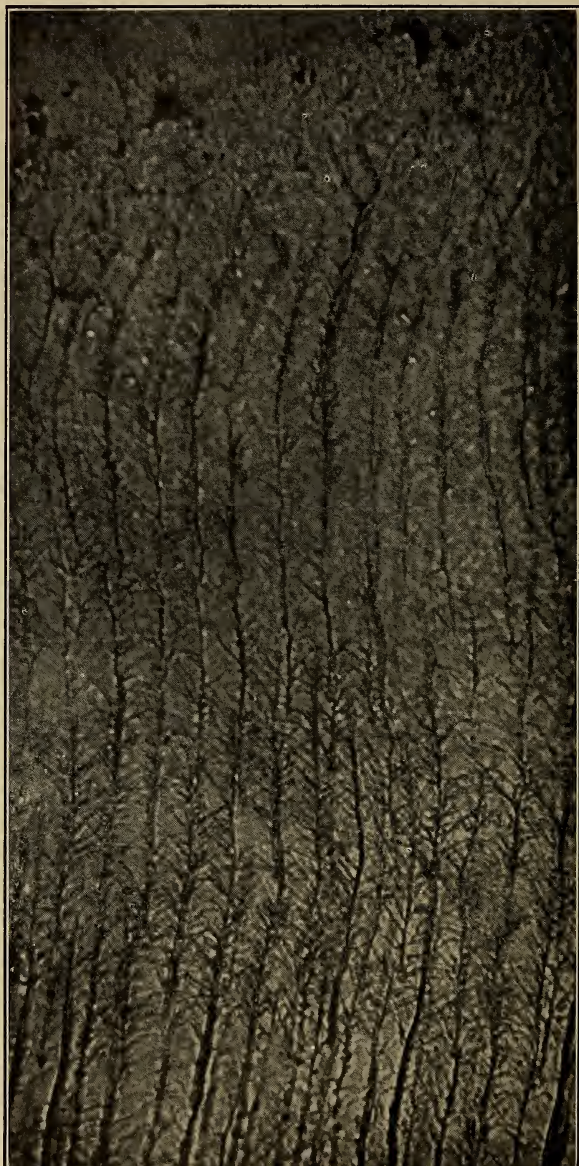


Fig. 123.—Dentin from the root, showing tubules cut longitudinally and the fine connecting branches. (About 700 ×)

dichotomously, each fork having about the same diameter as the original tubule (Fig. 122). These forkings of the tubules resemble the appearance of the delta of a river on the map. The branches anastomose with each other very freely. This anastomosis of the tubules at the dento-enamel junction is very important in determining the spreading of caries in this area. It probably also explains the sensitiveness of this area noticed in the preparation of cavities, which will be noted again in considering the sensitiveness of the dentin.

Fig. 124.—Granular layer of Tomes: *L*, lacunæ of cementum; *GT*, granular layer of Tomes; *Ig*, interglobular spaces. (About 200 ×)

The Dentinal Tubules in the Root Portion.—In the root portion of the dentin the tubules ordinarily show only the secondary curves, their general direction being at right angles to the axis of the pulp canal. Throughout their course they give off an enormous number of very fine branches extending from tubule to tubule. These are so numerous that in suitably prepared sections they may be said to look like the interlacing twigs of a thicket or the rootlets of plants in the soil. Fig. 123 gives a very good idea of the appearance.

At the dento-cemental junction the tubules end in irregular anastomosing spaces, which cause the appearance of the granular layer of Tomes (Fig. 124).

From a consideration of the preceding it will be seen that it is usually not difficult to determine whether a field of dentin seen under the microscope was taken from the crown or the root of a tooth. The structural characteristics of the two regions may be summarized as follows: In the *crown,* the tubules show both the primary and the secondary curves. In the *root,* the tubules show only the secondary curves. In the *crown,* the lateral branches are few and inconspicuous and the tubules branch in a characteristic way at the dento-enamel junction. In the *root,* the lateral branches are very numerous throughout the length of the tubule, and they end in the characteristic spaces of the granular layer of Tomes.

The Dentinal Fibrils.—In life the dentinal tubules are occupied by protoplasmic projections of the odontoblasts known as the dentinal fibrils, or fibers of Tomes. As the dentin matrix is formed and calcified under the influence of the odontoblasts, a portion of their protoplasm is left in the tubules of the matrix as the dentinal fibril. These structures were first described by John Tomes, who recognized their true character. They may be demonstrated in decalcified sections, and they will be seen projecting from the odontoblasts, when the pulp is removed from a freshly extracted tooth, by cracking it and picking the pulp out. In this way a portion of the fibril is pulled out of the tubules. The fibrils will be considered more especially in connection with the pulp, to which they properly belong.

In the author's opinion very little is positively known about the contents of the dentinal tubules. While it is very apparent that in young forming dentin the tubules are filled by cytoplasmic projections of the odontoblasts, it is by no means certain that all of the tubules of the dentin, in an old tooth are still occupied by living cytoplasm. What the fate of the cytoplasmic contents of the tubules is when secondary dentin is formed is not known. Several things are theoretically possible but there is little or no direct evidence on the matter.

The Granular Layer of Tomes.—The granular layer of Tomes is the outer layer of the dentin next to the cementum. The granular appearance is caused by irregular spaces in the dentin matrix which connect with the ends of the dentinal tubules, and which are filled with protoplasm continuous with that of the fibrils. Tomes first called attention to this layer, and for this reason it bears his name.

With magnifications of from 50 to 100 diameter it is easily seen in ground sections, either longitudinal or transverse, and appears as a layer filled with little dark spots or granules, the spaces which have been filled with the debris of grinding. It is separated from the cementum by a thin, clear layer, apparently of structureless dentin matrix, which is more apparent in higher magnifications. The granular layer is sometimes seen in the crown portion just under the enamel, but it is never as well marked in this position.

The layer is seen in sections ground from freshly extracted teeth as well as from old dry teeth, showing that these are true spaces and are not produced by the shrinkage of partially calcified dentin matrix. Tomes called the spaces in the granular layer "interglobular spaces," but this term should not be used, as the structures generally known as the interglobular spaces are different in location and character, and will be considered later.

The granular layer is not seen in decalcified sections. So far as the author is aware, no one has called attention to this fact before. In decalcified sections stained with hematoxylin and eosin the position of the granular layer is always occupied by a clear layer which takes the stain in an entirely different way from the rest of the dentin matrix, and in which no indication of spaces can be seen. While the fibrils in the tubules through most of the dentin take the hematoxylin stain and can be easily seen, they cannot be followed into this clear layer, and no indication of protoplasmic contents of irregular spaces can be seen.[1]

Dr. Skillen has worked out a method of demonstrating the granular layer of Tomes in decalcified sections which is reported in an article by Dr. Newton G. Thomas in the *Dental Cosmos* for June, 1920.

Most authorities state that the spaces of the granular layer communicate with the canaliculi of the cementum, as well as with the tubules of the dentin. This the author has been unable to

[1] The appearance of the tissue in decalcified sections had led to some doubt in the writer's mind as to the interpretation of the character of the layer by authors who have described it.

confirm. On the other hand, the granular layer seems to be separated from the cementum by a thin layer of dentin which is clear and apparently structureless. This is separated from the cementum by a dark line, and the first layer of cementum usually does not contain any lacunæ or canaliculi. This is supported by some of the experiments that have been made with extracted teeth. In experimenting on the diffusion of drugs through dentin, it was found that liquids sealed in the pulp chambers of extracted teeth could not be detected in the liquids in which the teeth were placed unless the cementum was removed from them. In the recent experiments of Dr. Southwell, of Milwaukee, in which air was forced through the dentin from the pulp chamber to test the sealing of cavities by filling materials, the air did not escape from the cementum, which would be the case if dentinal tubules connected with the canaliculi of the cementum.

If the spaces of the granular layer are filled with the protoplasmic enlargements of the ends of the dentinal fibrils, this would give a very reasonable explanation of the sensitiveness of slight caries and erosion at the gingival line, as the anastomosis through the granular layer would affect the fibrils of the entire tooth.

The Interglobular Spaces.—There has been considerable misunderstanding in dental histology in regard to these spaces, owing to the confusing of two entirely different things. Tomes called the spaces of the granular layer, which have already been described, interglobular spaces. As has been seen, they are true spaces in the dentin matrix which connect with the dentinal tubules and are filled with protoplasm.

In 1850 J. Czermak[1] described areas of imperfectly calcified dentin matrix, which appear as spaces in dried dentin, and called them interglobular spaces. These have been so called by most writers since. It seems important to the author that the term be restricted to these and some other used to indicate the spaces of the granular layer, which are of entirely different character.

The interglobular spaces of Czermak are caused by some disturbance in the calcification of the organic matrix of the dentin. They occur in zones (Fig. 125) which correspond to the dentin matrix, being calcified at a given time, and there is usually seen a corresponding disturbance in the calcification of the enamel, which was being formed at the same time and manifested as a more or less strongly marked band of Ritzius.

[1] Beitrag zur Mikro-Anatomie der Menschlichen-Zähne.

In the calcification of the dentin matrix the inorganic salts are combined with the organic matrix in spherical areas which become united. The boundaries of these areas of uncalcified matrix are

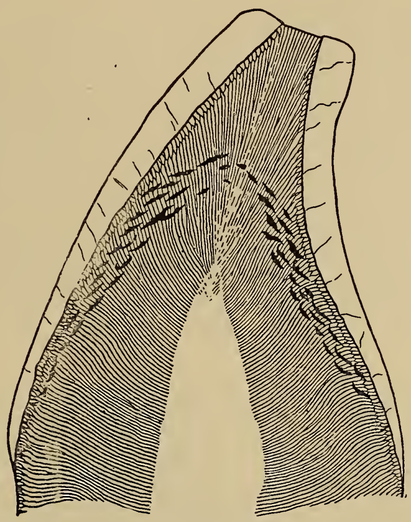


FIG. 125.—A drawing showing a zone of interglobular spaces in the dentin. (Black.)

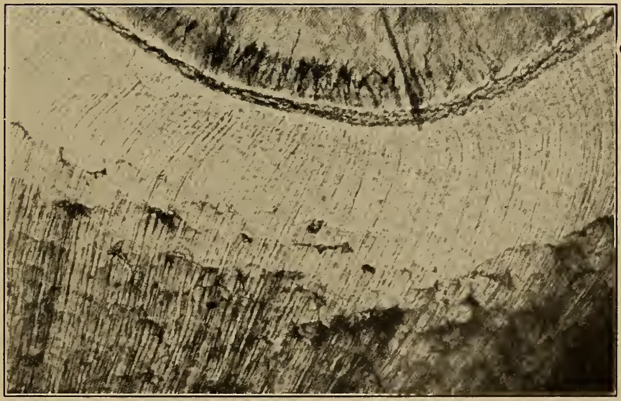


FIG. 126.—Interglobular spaces in dentin. (About 60 ×)

therefore very irregular, and made up of concave facets where they join the spherical surfaces of the fully calcified matrix (Figs. 126 and 127). A study of the illustrations and the appearance of the layer of forming dentin next to the dental papilla of a developing tooth will make this intelligible.

If the dentin is dried the organic matrix in these areas gives up

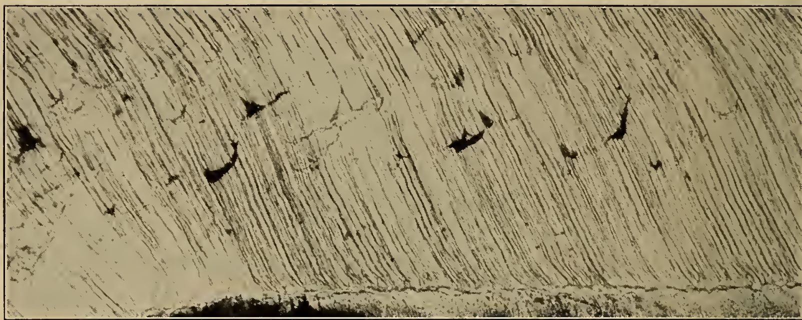


FIG. 127.—Interglobular spaces in dentin. Some empty, some filled with debris. (About 80 ×)

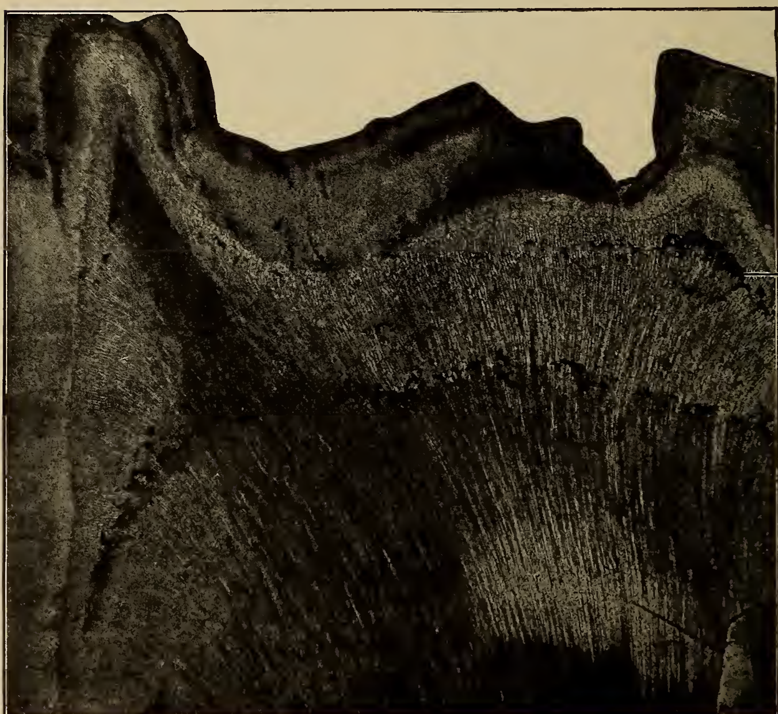


FIG. 128.—Interglobular spaces in dentin: *Ig*, first line of interglobular spaces; *Ig′*, second line of interglobular spaces. (About 30 ×)

water and shrinks, and the interglobular spaces become true spaces, partially filled with the shrunken matrix. In this condition they can be filled with colored collodion or any other material If, however, they are studied in sections of teeth which have never been allowed to dry, no space appears, and the dentinal tubules continue without change of course or diameter through the area. While they are, therefore, not empty spaces, they are areas of the organic basis of the dentin which are bounded by globular surfaces of the fully calcified matrix, and their name is properly significant.

Zones of interglobular spaces may occur at any portion of the dentin, either in the crown or root, but they are more common in the crown and near the enamel. Often more than one zone can be seen, as in Fig. 128, which shows two disturbances in calcification, and disturbances in the structure of the enamel will be seen at corresponding positions.

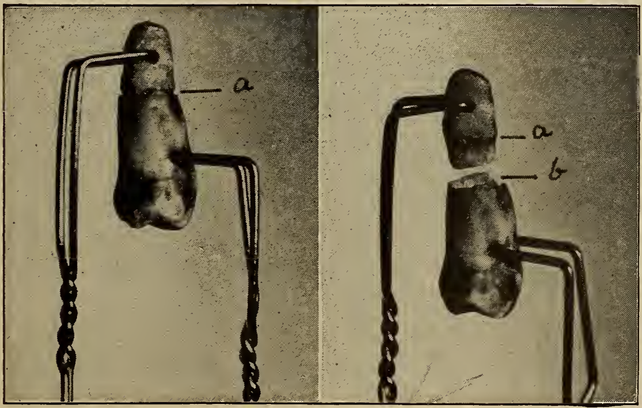


Fig. 129.—A root broken on a line of interglobular spaces. This tooth was extracted by Dr. G. V. Black, and was pulled apart in extraction. *a* shows the form of the root and *a*, *b* the separation on the line of growth. (Black.)

The zones of interglobular spaces appear in all grades, from a complete band of uncalcified matrix to widely scattered patches. Fig. 129 shows a tooth in Dr. Black's collection which was broken in extraction, because of the presence of such a zone in the root.

The interglobular spaces are of great importance in modifying the direction of the progress of caries in the dentin.

The Lines of Schreger.—As in the case of the interglobular spaces, there seems to be considerable misunderstanding in the literature and certain structures which have very different meanings have been called the "lines of Schreger."

An arrest in the formation of dentin often occurs before the crown is completed. When the activity has begun again the dentinal tubules follow a slightly different direction. In a longitudinal section this change in the direction of the tubules produces a line. Several such lines may be seen in a single section, though they are by no means to be found in all longitudinal sections.

Schreger's lines have been most often confused with zones of interglobular spaces, and they seem to be identical with the incremental lines in the dentin described by Owen. It is unfortunate that these names should have been used, for a thoughtful study of the tissue makes their interpretation perfectly evident, and they are of no great significance.

Secondary Dentin.—It is by no means easy to define secondary dentin or to pick out any particular piece of dentin in a section and to say whether it is primary or secondary. In general, the tubules are smaller, fewer, and less regularly arranged in secondary than in primary dentin. In general, it seems that the smaller the remainder of the dental papillæ becomes, the more imperfect dentin it forms, until finally it simply throws down granular calcified material.

The formation of dentin begins at the dento-enamel junction, at a number of points in each tooth, and progresses from without inward (strange to say, exactly the opposite statement has been made several times in papers by very prominent men). This matter will be taken up more in detail in the Chapters on Dental Embryology and Dentition. It is enough to say here that in studying all sections of dentin, whether cut longitudinally or transversely, the formation of dentin began at the dento-enamel junction and the dento-cemental junction, and progressed toward the pulp chamber.

From the study of longitudinal and transverse sections it is apparent that a certain typical amount of dentin is formed before the tooth is erupted and while it is coming into full occlusion. This is primary dentin. In it the tubules are very regular in size and arrangement. From this time on the formation of dentin is intermittent, and apparently is the response to some outside condition. These conditions may arise in the tooth in which the formation occurs, or the irritation of one tooth may cause tissue formation in all or part of the others. It has not been determined whether such reflex trophic stimuli are confined to the same lateral half or the same nerve distribution. Apparently the formation of dentin proceeds again, after a pause, in all teeth. It will seem, therefore, that the mere exposure of the entire crown to conditions of thermo-change produces sufficient stimulus to the pulp tissue to cause a renewal of dentin formation. After the first period of rest the dentin formed in the second period is so nearly identical, and the direction of the tubules so nearly the same, that it is usually impossible to recognize the junction except at a few points in the circum-

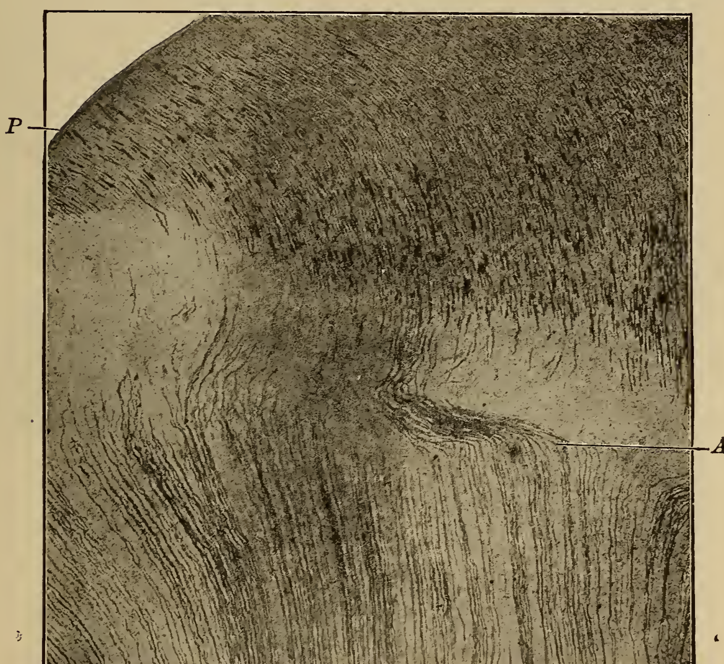


Fig. 130.—Secondary dentin: A, margin of primary dentin, showing a few of the tubules continuing into secondary dentin; P, pulp chamber. (About 80 ×)

ference of a transverse section. After each period of rest, however, the difference in structure between the succeeding portions becomes more marked. Fig. 130 shows an area from a longitudinal section when the line A was the pulpal wall of the dentin. There was probably a considerable period of rest, when for some reason a new formation of dentin was begun. But apparently only some of the odontoblasts took part in the new formation of dentin matrix, for not nearly all of the tubules are continued, and those that do continue show a sharp change in their direction and a difference in diameter and character (Figs. 131 and 132).

These characteristic changes in the structure of the dentin that is formed as the pulp becomes smaller seem to the author of great practical importance.

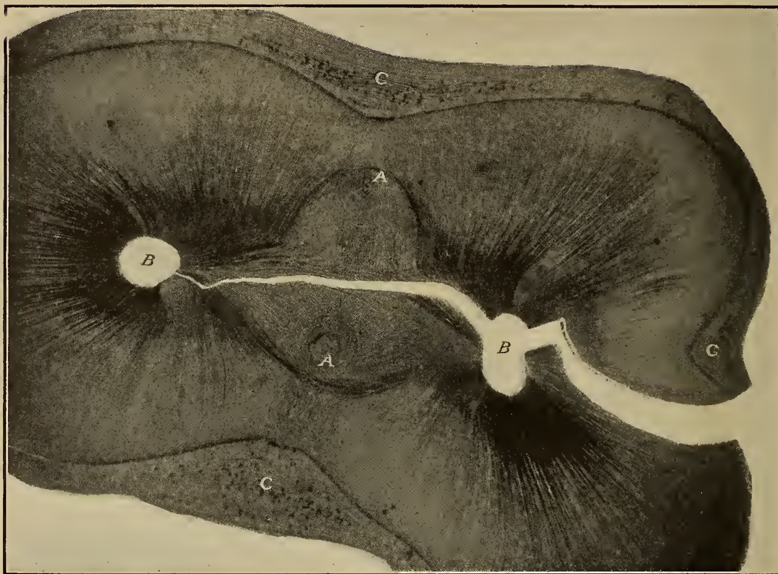


FIG. 131.—A transverse section of a root, showing the reduction in the size of the pulp and formation of secondary dentin: *A*, *A*, points at which the changes in the direction of the tubules show dentin formed at different periods; *C*, cementum thickened and each lamella thicker in the concavity of the dentin; also, the number of lacunæ greater.

FIG. 132.—A transverse section of a root, showing changes in the form of the pulp canal by the formation of secondary dentin.

CHAPTER XII.

THE CEMENTUM.

The cementum may be defined as a connective tissue whose intercellular substance is calcified and arranged in layers (lamellæ) around the circumference of a tooth root, the cells being found in spaces (lacunæ) irregularly placed in or between the layers.

Structurally the cementum is more closely related to the subperiosteal bone than any other tissue, the only differences being that in general the lacunæ in bone are much more uniform in size, shape, arrangement of the canaliculi, and their position with reference to the lamellæ than those in cementum. In bone the lacunæ are usually found between the lamellæ. In cementum the lacunæ may be between the lamellæ, but they are more often enclosed within their substance and they are found most often where the lamellæ are thick.

Some writers have described Haversian canals in the cementum, but the author has never seen anything that could properly be called an Haversian canal in the cementum from human teeth. Canals containing bloodvessels are not uncommon, but in these the lamellæ are never arranged concentrically around the canal, as they are in Haversian systems. For the last fifteen years the author has had under personal observation each year, in the course of class work, not less than 200 longitudinal sections, and 300 transverse sections of the root, ground from human teeth, and in that time he has never seen what could be called an Haversian canal. In the same time he has examined many hundreds of sections cut through the decalcified jaws of various mammals, including the sheep, pig, cat, and dog, with the same negative result.

Function.—The function of the cementum is to attach to the tooth the connective-tissue fibers which hold it in position and support the surrounding tissues.

The formation of cementum begins as soon as the tooth begins to erupt, and continues, at least intermittently, as long as the tooth remains in place, whether it contains a live pulp or not.

The function of the cementum cannot be too strongly emphasized, and must be continually borne in mind. If, for any reason, the tissues are detached from the surface of the root, they can only be reattached by the formation of a new layer of cementum on the surface of the root, which will embed the surrounding connective-tissue fibers. In order to accomplish this the tissues must lie in physiologic contact with the surface of the root, and the connective-tissue cells must be actively functional.

That the tissues may be reattached to the surface of a root is both theoretically possible and clinically demonstrable, but for it to occur, biological laws must be observed and the conditions are very difficult to control, especially with the old methods involving the excessive use of strong antiseptics. It is well to remember "that a dentist can never cure a suppurating pocket along the side of a tooth root," but if the conditions can be controlled the cells of the tissue may form a new layer of cementum, reattaching the tissues and so close the pocket. It is a biological problem, not a matter of drugs, except as they are a means of producing cellular reaction.

In view of its function, therefore, the cementum becomes not the least but the *most* important of the dental tissues, for no matter how perfect the crown may be, without firm attachment the tooth becomes useless and is soon lost.

Histogenesis.—The cementum is formed by connective-tissue cells lying between the fibers of the tissue which clothes the surface of the root and which becomes specialized for this function. Their origin is undoubtedly similar to that of the osteoblasts, but they are not osteoblasts, either morphologically or functionally, as will be seen later in the study of the peridental membrane, where the cementoblasts and the formation of cementum will be considered.

Structural Elements.—The structural elements of the cementum are:

1. The lamellæ.
2. The lacunæ and canaliculi.
3. The cement corpuscles.
4. The embedded fibers of the peridental membrane.

The Lamellæ of the Cementum and Their Arrangement.—The lamellæ of the cementum resemble those of bone, but they are very much more irregular both in thickness and appearance. They may be extremely thin and almost transparent, or they may be quite thick and coarsely granular. They are not nearly as easily observed as those of bone, for in bone the lamellæ are marked off by the lacunæ which lie between them, while in cementum the lacunæ may be entirely absent, and when present are irregularly placed.

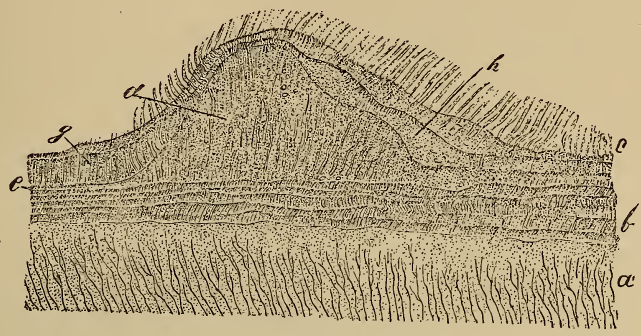


Fig. 133.—Hypertrophy of the cementum on the side of the root of a lower molar near the neck of the tooth. From a lengthwise section: human, *a*, dentin; *b*, cementum; *c*, fibers of peridental membrane. From *b* to *c* the cementum is normal and the incremental lines fairly regular, but at *d* one of the lamellæ is greatly thickened. At *e* this lamella is seen to be about equal in thickness with the others. The next two lamellæ are thin over the greatest prominence, but one is much thickened at *g*, and both at *h*. These latter seem to partially fill the valleys which were occasioned by the first irregular growth. (1 in. obj.)

In the gingival portion of the root the lamellæ are always thin and very transparent, and lacunæ are seldom seen. The entire thickness of the tissue is transparent, and the appearance of the

Fig. 134.—Hypertrophy from root of cuspid: human, in which the irregularity is confined to the first lamella: *a*, dentin; *b*, thickened first lamella; *c*, subsequent lamellæ, which are seen to be fairly regular. (1 in. obj.)

lamellæ can be seen only by using a very small diaphragm or oblique illumination. In this position the tissue is largely made up of embedded connective-tissue fibers, which are, however, so perfectly calcified that they cannot be demonstrated in ground sections. In decalcified sections they are very easily seen.

The cementum becomes gradually thicker in the middle third of the root, and is thickest in the apical third. It will be seen that this increase in thickness is caused chiefly by the greater thickness of each individual lamella. In longitudinal sections the cementum

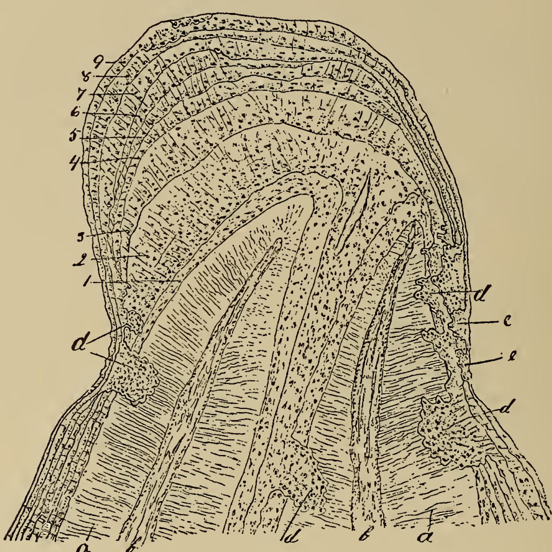


Fig. 135.—Apex of root of an upper bicuspid tooth with irregularly developed cementum: *a*, *a*, dentin; *b*, *b*, pulp canals. The lamellæ of cementum are marked 1, 2, 3, 4, 5, 6, 7, 8, 9; *d*, *d*, *d*, absorption areas that have been refilled with cementum. It will be seen that the apices of the roots were originally separate, but became fused with the deposit of the second lamella of cementum, and that in this the irregular growth began and was most pronounced. It has continued through the subsequent lamellæ, but in less degree. It will also be noticed that the absorption areas, *d*, *d*, *d*, have proceeded from certain lamellæ. That between the roots has broken through the first lamella and penetrated the dentin, and has been filled with the deposit of a second lamella. Other of the absorptions have proceeded from lamellæ which can be readily made out. The small points, *e*, seem to have been filled with the deposit of the last layer of the cementum, while others have one, two, or more layers covering them. (2 in. obj.)

is often found becoming suddenly thicker at a certain point, and if examined closely, it will be seen that each layer is continued apically, but with greater thickness. Fig. 135 illustrates this condition near the apex of the root. From a study of the lamellæ, therefore, it is apparent that the entire root is clothed with successive layers, and that these layers are formed intermittently, but continue to be formed as long as the tooth is in position. In a general way the number of layers is an index to the age of the person at the time the tooth was extracted (Figs. 136 and 137). The rate of formation is not uniform; for instance, a number of layers may be formed within a short time, and again, a considerable time may elapse between the formation of one layer and the next. The time, however, does not seem to determine the thickness of the layer.

If a considerable number of teeth of persons of twenty years of age were sectioned, the lamellæ counted, and this number compared with the number found in teeth extracted from persons of forty,

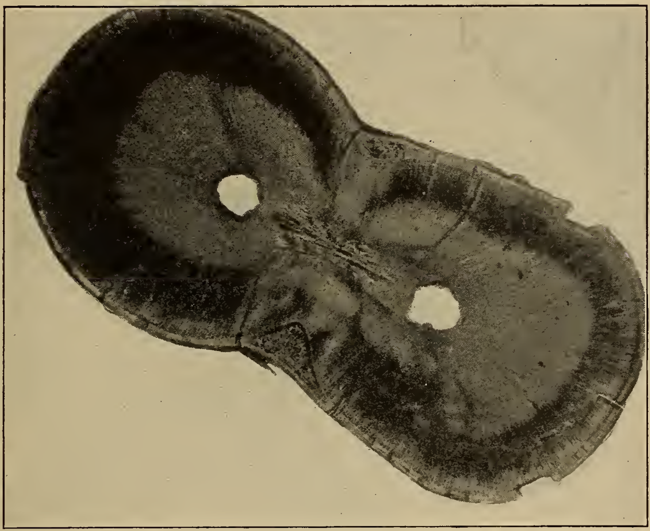


FIG. 136.—A transverse section of a root extracted from a young person. The cementum is thin, but is thicker in the grooves on the proximal sides.

a fairly regular increase in the number of layers will be noticed, and so on, for fifty, sixty, seventy, or eighty years.

It is important to remember in connection with this formation of cementum that the teeth move, more or less, under the influence of natural forces throughout life, and that every slight change in position must be accomplished by the formation of a new layer of cementum, to reattach connective-tissue fibers in new positions or adjust them to new directions of strain.

The first layer of cementum is formed while the tooth is still in its crypt, but apparently no connective-tissue fibers are calcified into it. This forms the first apparently clear and structureless layer which lies next to the granular layer of Tomes (Fig. 138). Even in the teeth the entire length of whose roots are formed before they begin to erupt, there is no attachment until some stress comes upon the crown. The tooth is lying loose in its crypt and can be picked out with very little force. Bicuspids are often accidentally extracted in the extraction of temporary molars. As soon as

Fig. 137.—A transverse section of a root from an old person. This root had carried a crown for many years. The section was cracked and one edge broken.

the tooth comes through the gum a new layer of cementum is formed over the entire root, attaching the fibers to its surface, and as the tooth moves occlusally, layer after layer is formed. This will be considered again in connection with the peridental membrane.

The Lacunæ and Canaliculi.—The lacunæ of the cementum correspond with the lacunæ of bone. They differ from those of bone, however, in that they are more irregular in shape, size, position, and relation to the lamellæ, and in the number and direction of the canaliculi radiating from them. In bone the lacunæ are fairly regular in shape, the long diameter exceeding the short diameter by about one-third. Sections cut through their long axis give an oval outline, the length of which is about three times as great as the width. Sections cut through their short axis give an oval outline, the long diameter being about twice that of the short. The spaces are therefore flattened between the lamellæ. In

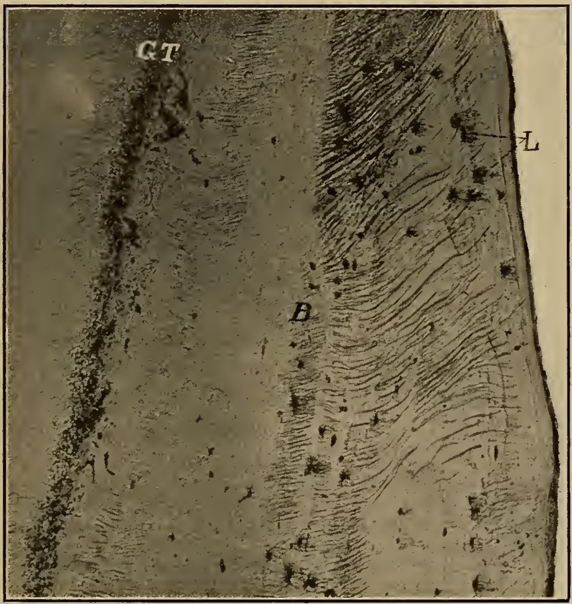


FIG. 138.—Cementum near the apex of the root: *GT*, granular layer of Tomes; *L*, lacunæ; *B*, point at which fibers were cut off and reattached. (About 54 ×)

cementum there is no regularity whatever, either in size or in shape. Some are a little larger than the lacunæ in bone, some are very much smaller. They may be almost exactly the shape of typical bone lacunæ or they may be distorted into almost any form, sometimes being almost stellate, often pear-shaped, sometimes round, and occasionally pyramidal. The lacunæ of bone are fairly uniformly placed, and lie between one lamella and the next.[1] There is no

[1] This is not absolutely correct, there being much more irregularity in the arrangement of the lacunæ in thick subperiosteal bone than in either cancellous or Haversian system bone. To be strictly accurate, the above statement must be limited to Haversian system bone (Plate XIII).

regularity in the relation of the lacunæ of the cementum to the lamellæ. They sometimes lie between one lamella and the next, but they are more often entirely in the substance of one. They occur only where the lamellæ are thick, and there may be large areas with considerable aggregate thickness of cementum in which there are no lacunæ at all.

The number and direction of the canaliculi which radiate from the lacunæ of cementum is extremely irregular, but in general there are more extending from the lacunæ toward the surface than toward the dentin.

The Cement Corpuscles. — The cement corpuscles correspond exactly to bone corpuscles. They are the cells found in the lacunæ. These are simply embedded cementoblasts and are typical connective-tissue cells. They are made up of granular cytoplasm and contain a faintly staining nucleus. Extensions of the protoplasm undoubtedly extend into the canaliculi. These cells bear the same relation to the matrix of the cementum that bone corpuscles do to that of bone. What this is, is not known in any definite way, but it is known that when bone corpuscles are killed or die, the matrix becomes a foreign body, and is either absorbed or cut off from the portion in which the corpuscles are living, to be absorbed or cast out as a sequestrum. The same conditions are true of cementum. For instance, there are many cement corpuscles in the lacunæ in the region of the apex of the root. If this portion be bathed in pus for a long time, the cement corpuscles are killed, and the tissue becomes saturated with poisonous materials, so that tissue cells cannot lie in contact with it and live. In order to restore a healthy condition, the necrosed cementum must be removed mechanically until tissue is reached with which cells may lie in physiological contact without injury. Conditions which can only be understood through a knowledge of the structure of the tissue often arise in connection with the treatment of alveolar abscess. It should always be remembered that the treatment of an abscess is a biological problem.

The Embedded Fibers of the Peridental Membrane.—The embedded fibers of the peridental membrane are in the strictest sense comparable with the fibers of Sharpe in bone. They are, however, in many places much more perfectly calcified. To appreciate the relation of the embedded fibers to the matrix, the tissue must be studied both in ground and decalcified sections. For instance, in the gingival portion, from the study of ground sections, the presence of embedded fibers would never be suspected, but if decalcified sections are studied it will be found to be almost entirely composed of calcified fibers. In the middle and apical thirds of the root, where the lamellæ are thicker, the calcification of these fibers is often not as perfect as that of the rest of the matrix. In the preparation of ground sections, therefore, the imperfectly calcified fibers

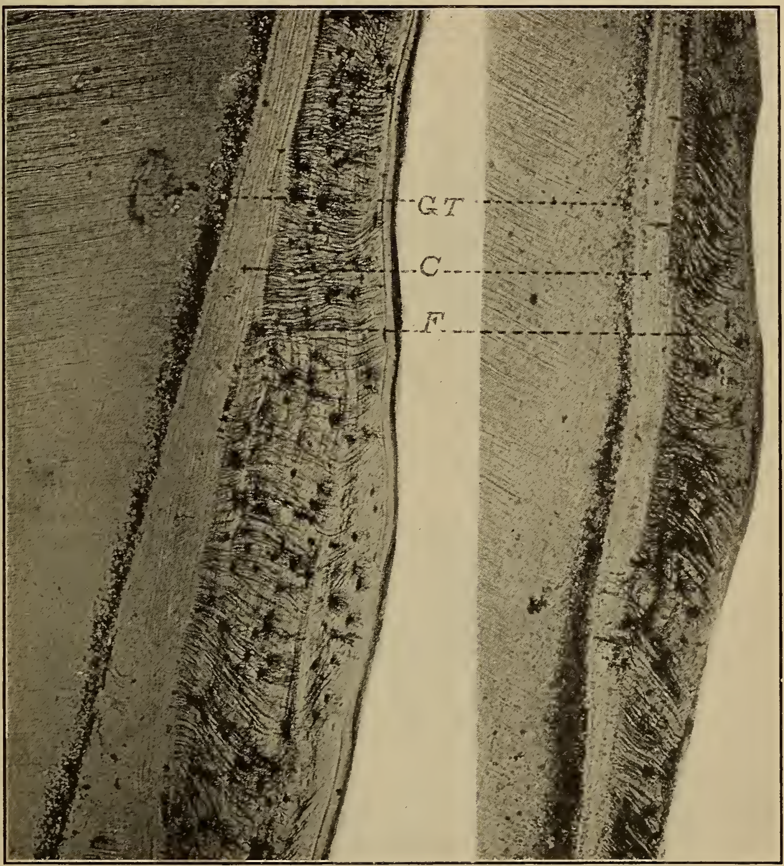


Fig. 139.—Two fields of cementum showing penetrating fibers: *GT*, granular layer of Tomes; *C*, cementum not showing fibers; *F*, penetrating fibers. (About 54 ×)

shrink and consequently appear as canals in the cementum. In fact, they have often been mistaken for canals. They are usually not seen unless the section happens to cut in their direction. These will be seen in many of the illustrations of cementum. In Fig. 138 several layers are seen next to the dentin, in which no fibers appear, then in several layers the fibers are plainly seen, and finally, the surface layers show no fibers. This probably means that before and after these layers were formed there was a change in the position

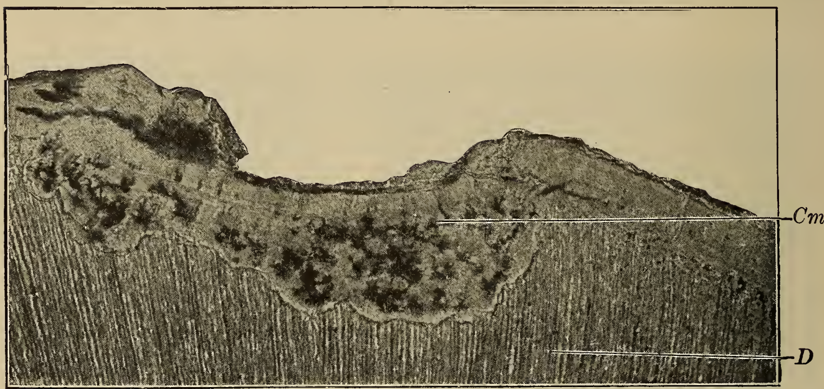


Fig. 140.—Record in the calcified tissue of an absorption repaired: *D*, dentin; *Cm*, cementum filling absorption cavity. (About 40 ×)

of the tooth and the fibers were all cut off in this area and reattached in a new direction, adapting them to the new directions of strain.

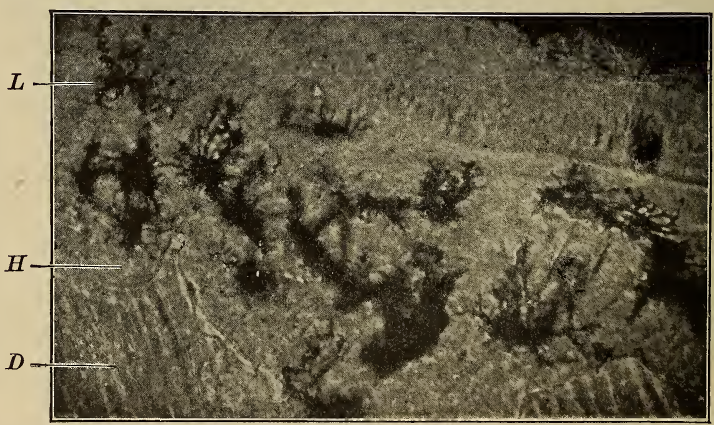


Fig. 141.—Thick lamellæ of cementum with many lacunæ, filling an absorption in dentin: *L*, lacunæ; *H*, Howship's lacunæ filled; *D*, dentin. (About 250 ×)

It is often necessary to study ground sections very closely to determine whether certain appearances are embedded fibers or canaliculi radiating from the lacunæ. The appearance of these fibers should be studied in Fig. 139. It should be noted that wherever special stress is exerted upon a bundle of fibers the cementum is thick around them. This may be seen in decalcified sections in Figs. 204, 231 and Plate XVII and in ground sections in Figs. 138 and 139. When the next layer is formed, if the fibers are cut off, the additional thickness of the last layer is removed. The unequal thickness of the last formed layer is not usually seen in the layers beneath it to as great an extent.

Absorption and Repair of the Cementum.—From what has already been said about the cementum, it will be understood that this tissue is continually undergoing changes, that new layers are being added, and that often before an addition is made there is absorption enough of it at least to cut off the fibers. When an absorption occurs on the side of a root which cuts into the dentin, the excavation in the dentin may be filled by the cementum subsequently formed (Figs. 140 and 141). From a study of ground sections in class work such absorptions are not uncommon. They probably occur when the cusps first come into occlusion in eruption.

CHAPTER XIII.

DENTAL PULP.

Definition.—The dental pulp may be defined as the connective tissue occupying the central cavity of the dentin.

It is composed of embryonal connective tissue which is more closely related to the tissue occupying the spaces of cancellous bone than to any other.

Functions.—The functions of the dental pulp are:

1. A vital function, the formation of dentin.
2. A sensory function responding to thermal and chemical change and traumatic irritation.

Vital Function.—The vital function is the formation of dentin and is performed by the layer of odontoblasts. These cells also, by means of their dentinal fibrils, maintain the same relation to the dentin matrix that the bone and cement corpuscles bear to the matrix of bone and cementum. When the pulp is removed from a tooth its dentin becomes dead dentin in the same sense that bone in which the bone corpuscles have been killed is necrosed bone. That there is a constant reaction between the protoplasm of the odontoblasts and the substance of the dentin matrix, or that the presence of the living protoplasm is necessary to prevent degeneration of the matrix, is evidenced by the changes in the physical properties of the dentin after the pulp has been lost. That the tooth remains functional after the loss of the pulp is due to the fact that, except at the minute foramina, the dentin is not in physiologic contact with any tissue excepting enamel and cementum, and that the cementum attaches the tooth to the surrounding tissues, receiving its nourishment from the surface and not from the dentin.

When the pulp is removed and its place filled by a non-irritating material, the dentin becomes entirely encased in cementum, the foramina probably being covered over as the subsequent lamellæ are formed. The author wishes to emphasize, however, the vital relations of the pulp to the dentin matrix. Dead dentin is never as good as living dentin, consequently a tooth from which the pulp has been removed can never be considered just as good as one with the living pulp.

The production of the dentin matrix is, of course, the principal part of the vital function of the pulp. It is begun in the development of the tooth before the dental papilla is converted into the dental pulp, by being enclosed in the dentin formed. After the tooth is fully formed the pulp retains its ability to build dentin matrix as long as it retains vitality, but this function is exercised only in response to conditions of environment which are probably excited through the intervention of its sensory function responding to thermal change and chemical irritation. The sensory function causes a trophic impulse which is manifested by the production of another portion of dentin matrix reducing the size of the pulp chamber. That this is a reflex and not purely a local matter is indicated by the fact that formations of dentin occur in one tooth when the irritation is in another, and apparently the irritation of one tooth will excite dentin formation in all of the teeth on that side, at least in some instances. On the other hand, purely local responses are found where a few odontoblasts respond to the irritation of their fibrils by the formation of dentin.

This matter has been referred to under the heading of Secondary Dentin, and it is best studied by the record it leaves in the formed tissue.

The Sensory Function.—In regard to sensation, the pulp resembles an internal organ, as in its normal condition it is always enclosed in the cavity of the dentin. It has no sense of touch or localization, and responds to stimuli only by sensations of pain. The pain is usually located correctly with reference to the median line, but apart from that it is located only as it is referred to some known lesion. If several pulps were exposed on the same side of the mouth, and in teeth of both the upper and lower arches, so that they could be irritated without impressions reaching the peridental membrane, if the patient were blindfolded it would be impossible for him to tell which of the pulps was touched. This characteristic becomes extremely important in diagnosis.

The pain originating from a tooth pulp may be referred to the wrong tooth or to almost any point on the same side supplied by the fifth cranial nerve.

The dental pulp is especially sensitive to changes in temperature, amounting almost to a temperature sense, having no exact parallel in any other tissue of the body. This does not amount to a recognition of heat or cold as such, but a special resentment to sudden changes. For instance, if a tooth is isolated and so protected by non-conductors that the soft tissues cannot be stimulated, and a jet of hot and then cold water be thrown upon its crown, it will respond to each with a sharp sensation of pain, but the patient cannot tell which is hot and which is cold. It is the sudden change that produces the reaction. This is the basis of very important differential diagnosis, for, as is true with most organs, in pathologic conditions its sensory function is exaggerated.

Histogenesis.—The dental pulp is the remains of the dental papilla; the dental papillæ for the temporary teeth appearing in the mesodermal tissue of the jaw arches very early in fetal life. The cellular elements are at first very closely placed and large, but they grow smaller and take on the typical form of pulp cells as the intercellular substance is increased. By the sixteenth week the dental papillæ for the temporary teeth are covered by a layer of tall columnar cells, which will begin the formation of dentin about that time. After the beginning of dentin formation the transition from the dental papillæ to the dental pulp is very gradual, and it would be impossible to draw any sharp line of demarcation between them.

Structural Elements.—The structural elements of the dental pulp are:

1. Odontoblasts.
2. Connective-tissue cells.
3. Intercellular substance.
4. Bloodvessels.
5. Nerves.
6. Lymphatic vessels.

The Odontoblasts.—The odontoblasts are tall columnar cells which form the outer layer of the pulp adjacent to the dentin, and from which cytoplasmic fibrils extend into the dentinal tubules.

The character of the odontoblasts changes very greatly with the age of the tissue, and the activity of dentin formation. While the primary dentin is being formed they are tall columnar cells, each containing a large oval nucleus, rich in chromatin and located in the pulpal third of the cell. From the dentinal end of the cell cytoplasm is continued, without any line of demarcation, into the dentinal tubule as the dentinal fibril. In some instances two fibrils may be sent from a single odontoblast. The character of the odontoblast is beautifully seen in Fig. 142, a photograph by Professor Röse.

After the tooth is erupted, but while the formation of dentin is actively going on, the odontoblasts, while somewhat smaller,

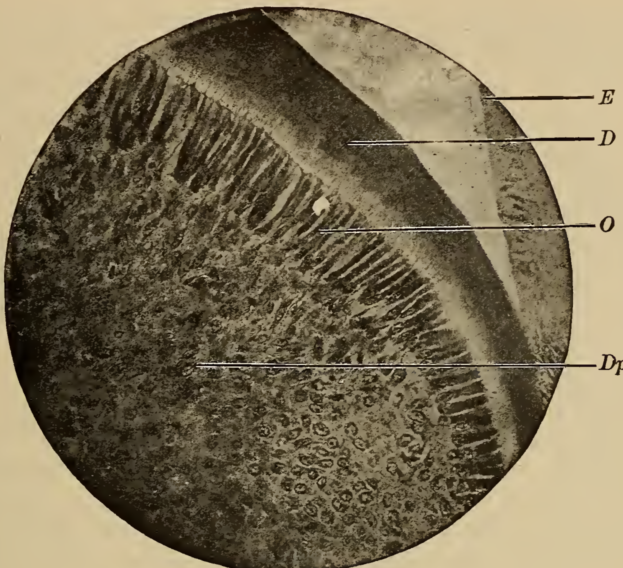


FIG. 142.—Odontoblasts and forming dentin: *E*, forming enamel; *D*, forming dentin; *O*, odontoblasts; *Dp*, body of dental papilla. (From photomicrograph by Röse.)

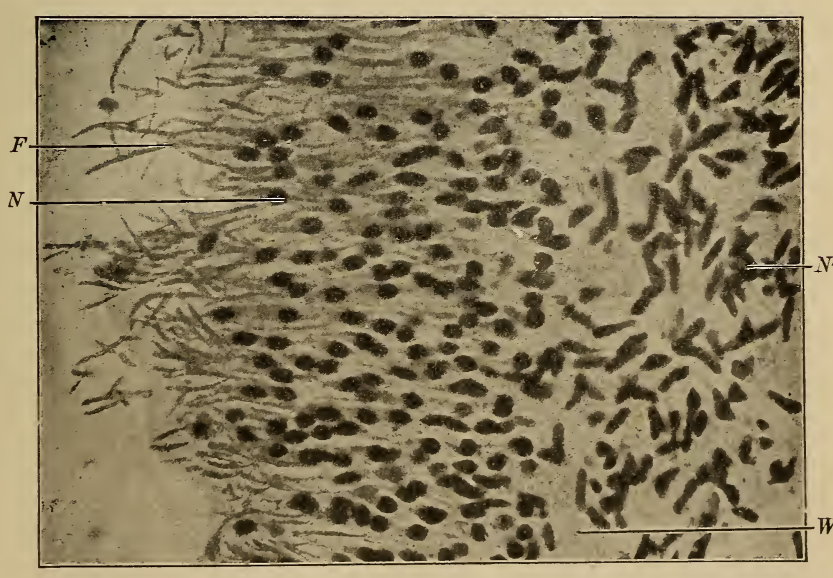


FIG. 143.—Odontoblasts. The section cuts obliquely through the odontoblasts: *F*, fibrils; *N*, nuclei of odontoblasts; *N'*, nuclei of connective-tissue cells; *W*, layer of Weil, not well shown. (About 80 ×)

retain the same typical appearance. They may be easily demonstrated either in decalcified sections or by removing pulps from the pulp chamber of freshly extracted teeth. Professor Salter has described two sets of processes besides (Fig. 144) the dentinal fibril process. As a result of teasing the fresh pulps, he considered that fine projections of the cytoplasm extended from the sides of the cells, uniting them to the adjoining odontoblasts (Fig. 144). These he called the lateral processes. He also described cytoplasmic projections from the pulpal end of the odontoblasts into the layer of Weil. It is probable that these appearances were the result of teasing, and are not true structural characteristics, as the work of other investigators has not confirmed their presence. It is easy to understand how teasing the cells apart might produce appearances which might be interpreted as processes, but careful work upon sections does not show their presence.

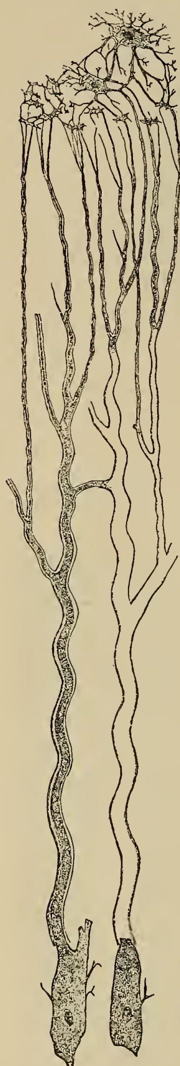


Fig. 144.—Diagram of odontoblasts and dentinal fibrils. (C. H. Stowell.)

In old pulps where the formation of dentin has been intermittent and very infrequent for a long time, the odontoblasts are smaller, lose their columnar form more or less, and become pear-shaped or globular.

As dentin is one of the most highly specialized connective tissues, the odontoblasts are among the most highly differentiated connective-tissue cells. They are the only connective-tissue cells of columnar form. Morphologically, they are very similar to columnar epithelium, but epithelial cells never have such processes as the dentinal fibrils. Occasionally, in young and actively growing bone, osteoblasts are found which are distinctly columnar in form, but they are never as tall as the odontoblasts, and the nucleus is more nearly in the center of the cell. In the case of the osteoblast the cytoplasmic processes which extend into the canaliculi correspond to the dentinal fibril process of the odontoblast. The homologies between the osteoblasts and the odontoblasts have often been lost sight of in the discussions over the character of the latter and their relation to the formation and sensitiveness of the dentin.

The Membrana Eboris.—The odontoblasts form a single layer of cells on the surface of the pulp in contact with the dentin. This layer was very early recognized to be related to the formation of the dentin, and was called the *membrana eboris*, or the membrane of the ivory. The name has no importance now except as it is found in the literature.

Size of the Odontoblasts.—From what has been said it will be recognized that the size and shape of the odontoblasts vary greatly in different sections. This is true not only of pulps from different animals, and pulps at different periods of development, but of different parts of the same pulp. In the coronal portion of a pulp from a fully developed tooth, but one in which the formation of dentin is still going on, the average measurements would be about 5μ in diameter and 25 to 30μ in height. During early stages of dentin formation, before the crown is fully formed, they are considerably larger and taller, and in the pulps of a calf they are much larger than in smaller animals and man. In a constricted pulp, as, for instance, in the mesial root of a lower first molar, the odontoblasts on the constricted sides will be shorter and relatively thicker than on the buccal and lingual, where the long axis of the cell is in the direction of the long diameter of the pulp, but this simply means that the formation of dentin on the constricted side is relatively farther advanced than on the buccal and lingual, and the cells show older phases. It is evident that the supply of nourishment to the cells in the constricted portions is more imperfect, and that the ones farthest from the main vessels are most affected, so that dentin formation is slowed and made more imperfect here, while it still continues in full vigor around the expanded portions of the pulp. This has been spoken of in connection with the study of the dentin (see Figs. 131 and 132).

Origin of the Odontoblasts.—The odontoblasts are specialized connective-tissue cells. It is therefore to be expected that they should be formed from undifferentiated connective-tissue cells, as osteoblasts are formed from similar cells of the inner layer of the periosteum and embryonal cells of the tissue filling the cancellous and marrow spaces. The odontoblasts are therefore developed from embryonal cells deeper in the pulp which take their place in the odontoblastic layer. This probably explains the appearance of some sections, and also, the author believes, the views of some men in regard to the odontoblasts and the dentinal fibrils. In some sections from old pulps the odontoblasts seem to be in an incomplete layer, and their form is more like that of typical connective-tissue cells.

In considering the origin of the odontoblasts it should be noted: That in the first differentiation of these cells in the embryo. They appear first where epidermal cells (inner tunic of the enamel organ) are in contact with mesodermal cells (the outer layer of the dental papilla). This is true in the formation of the entire length of the root—the enamel organ—extending on down the dental papilla beyond the point where enamel formation stops. (See Chapter XXVI). The author believes that the meaning and importance of this relationship has not yet been grasped.

Connective-tissue Cells.—The cells in the dental pulp, aside from the odontoblasts, are typical connective-tissue cells such as are found in embryonal tissue. They are of three forms—round, spindle-shaped, and stellate. In the crown or bulbous portion the cells are mostly stellate, while in the root portion they are largely spindle-shaped, with the axis of the spindle parallel with the canal. It seems difficult for students to get an idea of their arrangement, and the nucleus is often mistaken for the entire cell. The cells do not lie in contact in a compact tissue, but are widely scattered in the intercellular substance. There is a small ovoid nucleus, which takes the stain deeply, surrounded by a mass of granular cytoplasm stretching away into very fine threads. In the spindle-shaped cells the cytoplasm is stretched out in only two directions. In the stellate cells there may be three, four, or more, stretching away in any direction. Plate IX was very carefully drawn with the camera lucida so as to represent accurately the number, size, and position of the cells in that field as seen with the $\frac{1}{12}$ oil immersion. It is very difficult in a drawing to represent the third dimension of space, and to show that some of the processes are extending in a plane at right angles to the paper. An idea of this can only be obtained by the very careful use of the fine adjustment while studying the cells with the high power.

The round cells are probably white blood corpuscles or undifferentiated connective-tissue cells which may develop either into stellate or spindle-shaped.

The Arrangement of the Cells.—Immediately beneath the layer of odontoblasts, for a space about one-half or two-thirds as wide

PLATE IX

A Field from the Coronal Portion of the Pulp from a Human Molar.

In the corner the stage micrometer shows $\frac{1}{100}$ of a millimeter drawn with the same lens. The field shows the branching of a bloodvessel and the connective-tissue cells of the pulp. Drawn from $\frac{1}{12}$ oil-immersion lens with camera lucida. (About 1200 X.)

as the odontoblastic layer, the cells are very scarce, making a clear line in many sections. This is known as the layer of Weil, and contains many fine nerve fibers which are not stained by ordinary methods. Beyond the layer of Weil for a space perhaps twice as wide as the height of the odontoblasts, the cells are very closely placed. Through the remainder of the pulp they are much more widely but comparatively evenly scattered.

The Intercellular Substance.—Very little is really known about the character of the intercellular substance of the pulp. It contains few fibers, and these in no way resemble bundles of white or elastic connective tissue. The appearance in the section is more as if a structureless gelatinous material had been coagulated by the reagents.

There are, of course, connective-tissue fibers in connection with the walls of the larger bloodvessels and nerves, and to a certain extent in the gelatinous material. In studying the intercellular substance in the sections it is necessary to remember that it is filled with the protoplasmic projections from the cells, and these are stained, appearing like fibers in the matrix. There is need for further investigation of the character of the intercellular substance.

The Bloodvessels.—The dental pulp is an extremely vascular tissue, and the arrangement of the vessels, the structure of their walls, and the nature of the intercellular substance through which they run render the tissue especially susceptible to the pathological conditions which are associated with alterations in the circulation.

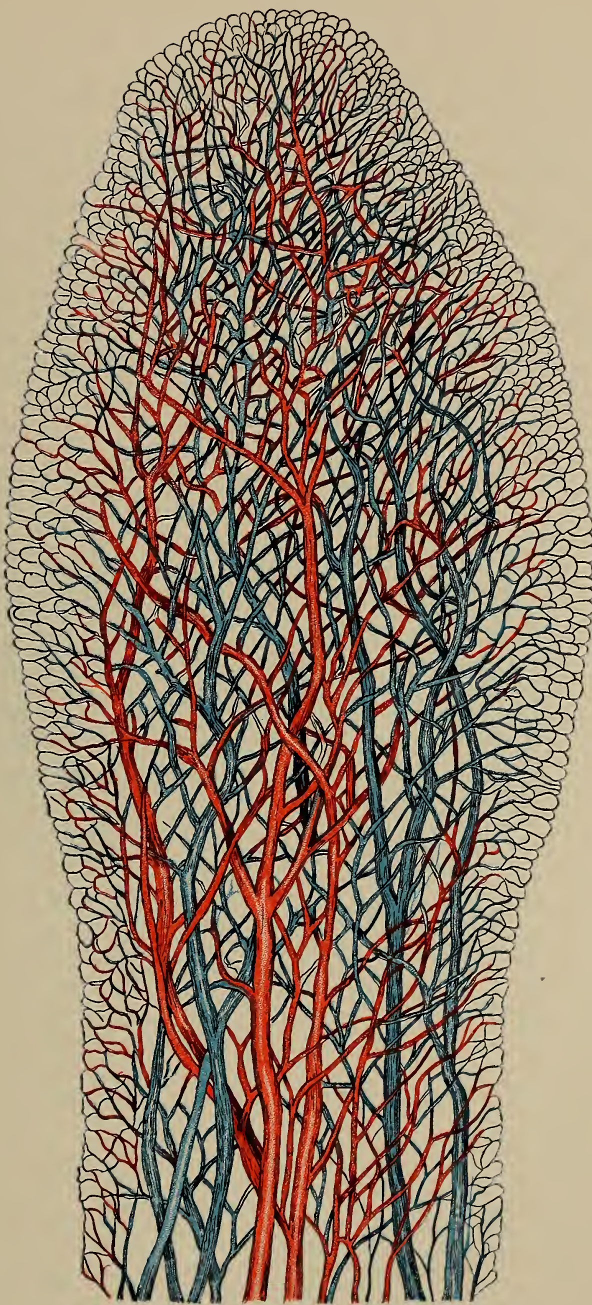
Usually several arterial vessels enter the pulp through foramina in the region of the apex. These vessels have their origin in the rich vascular network of the cancellous bone (chapter on Peridental Membrane). The arteries follow the central portion of the pulp, giving off many branches as they pass occlusally, and finally form a very rich plexus of capillaries near the surface of the pulp. From these capillaries the blood is collected into the veins, which follow courses parallel to the arteries, leaving the pulp through the same foramina in the region of the apex. It is important to notice that an artery is entering and a vein leaving the tissue through very minute canals in the calcified dentin (Fig. 145). Dr. Stowell has made a very beautiful diagram of the arrangement of the bloodvessels in a single-rooted tooth, which is shown in Plate X. Preparations such as would reproduce this diagram can be made by injecting the bloodvessels with an inert material and destroying the soft tissues by artificial digestion.

Toward the periphery of the pulp very delicate vessels pass outward terminating in loops just beneath the odontoblasts. These are shown in Fig. 146.

FIG. 145.—A section through the apex of a root showing three foraminæ, *A*, *B*, and *C*. (Talbot.)

Structure.—The delicacy of the walls of the bloodvessels is one of the most striking histologic characteristics of the dental pulp.

PLATE X



Bloodvessels of the Dental Pulp. (After Stowell.)

A well-injected pulp studied under a binocular microscope makes a very beautiful object which no flat picture can represent. The larger bloodvessels lying at the centre branch and divide, forming a network which becomes very fine at the surface.

The largest arteries show only a few muscle fibers in the media and a very slight condensation of fibrous tissue for an adventitia. There is no distinct boundary between the capillaries and the veins, and the vessels continue to have only a wall of endothelial cells after they have reached a size much greater than that of capillaries. Because of this peculiarity of structure the statement is to be found in many text-books of histology that the largest capillaries in the body are found in the dental pulp. These vessels should probably not be considered as capillaries, but as veins whose walls have the structure of capillaries. Even in the largest veins the media is very

FIG. 146.—Dental pulp showing bloodvessel loops extending to the periphery, close to the layer of odontoblasts.

imperfect, and there is only a slight condensation of fibrous tissue to represent the adventitia. This peculiarity of the bloodvessel walls in the pulp renders the tissue peculiarly susceptible to hyperemia and inflammation.

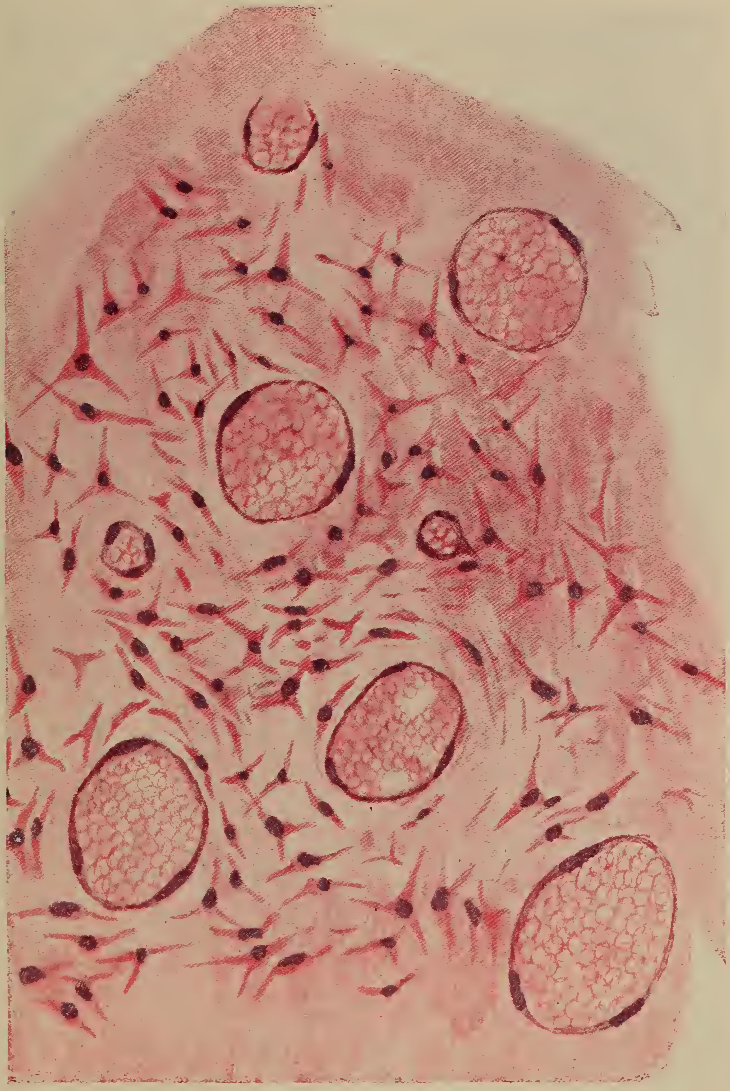
Fig. 147 is a photograph of a bloodvessel whose size can be estimated from the number of red corpuscles seen in it, and the wall is made up of a single layer of endothelial cells. There is no indication of either media or adventitia. The intercellular substance of the pulp being of gelatinous, semifluid character, gives no support to these delicate walls.

In Plate IX the author has drawn very carefully, with the camera lucida, using a $\frac{1}{12}$ immersion lens, a field showing the branching of a small bloodvessel. The size of the endothelial cells, position of their nuclei in the wall of the vessel, and the size, position, and shape of the connective-tissue cells, are represented as accurately as possible. The field is from the coronal portion of the pulp of a human molar. The caliber of such a vessel as this would depend

Fig. 147.—A pulp bloodvessel, showing the thin wall: *C*, blood corpuscles in the vessel; *Bl*, bloodvessel wall showing nuclei of endothelial cells; *N*, nuclei of connective-tissue cells in the body of the pulp; *I*, intercellular substance, showing a few fibers. (About 200 ×)

almost entirely upon the blood-pressure. The endothelial cells will stretch to a very considerable extent under increased pressure, becoming very thin at all points except around the nucleus. When the pressure is decreased the contractility of the cytoplasm pulls the cells together, making it thicker and less in diameter. It is very important to remember these facts in connection with hyperemia of the dental pulp. It is difficult in such an illustration to give any representation of the third dimension of space, which

PLATE XI



A Field from the Pulp of an Unerupted Tooth of a Sheep.

The bloodvessels are cut transversely. (About 1000 X.)

is essential to a real understanding of the connective-tissue cells of the pulp. These are bits of cytoplasm with a nucleus forming a small, irregular central mass, from which the cytoplasm is stretched away in all directions through the intercellular substance, ending in very fine threads.

Plate XI is drawn in the same way from a transverse section of the pulp of an unerupted tooth of a sheep. The vessels are all cut transversely and are seen crowded with red blood corpuscles. They are not distended, and some show slight condensation of fibrous tissue around them.

In a normal pulp there are many capillaries so small that a single corpuscle passes them with difficulty, but in pathologic conditions they become distended to many times their normal diameter.

Lymphatics of the Dental Pulp.—It was for a long time believed that the dental pulp contained no lymphatic vessels. In 1907–1909, Schweitzer succeeded in injecting lymphatic vessels in the pulp.[1] In 1916–1917 Dr. K. Dewey and the author repeated the work of Schweitzer in the Histological Laboratory of the College of Dentistry University of Illinois, and also succeeded in injecting the lymphatic glands of the neck in dogs by injections in the dental pulp.[2]

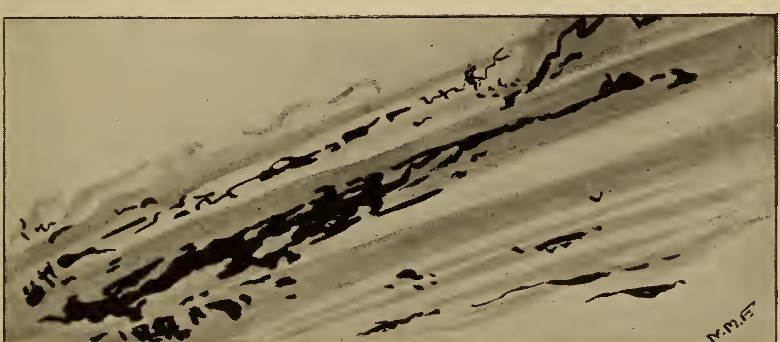


Fig. 148

Fig. 148 shows a portion of the pulp of a young dog. The blood-vessels are injected with gelatin carmin, the lymphatics with Berlin blue. Very fine vessels were found close to the surface of the dentin (Fig. 149). From these capillaries vessels pass through the

[1] Schweitzer: Ueber die lymphgefässe des Zahnfleisches und der Zähne beim Menschen und bei Saügethieren, Archiv. f. Micr. Anat., 1907, p. 807, 1909, p. 27.

[2] A Study of the Lymphatic Vessels of the Dental Pulp, Dental Cosmos, vol. lix, 1917, pp. 436–44; Journal of the American Medical Association. Oct. 12–1918, vol. ii, pp. 1179–1184.

central portions of the tissue and pass through the apical foramina where they anastomose with the vessels of the peridental mem-

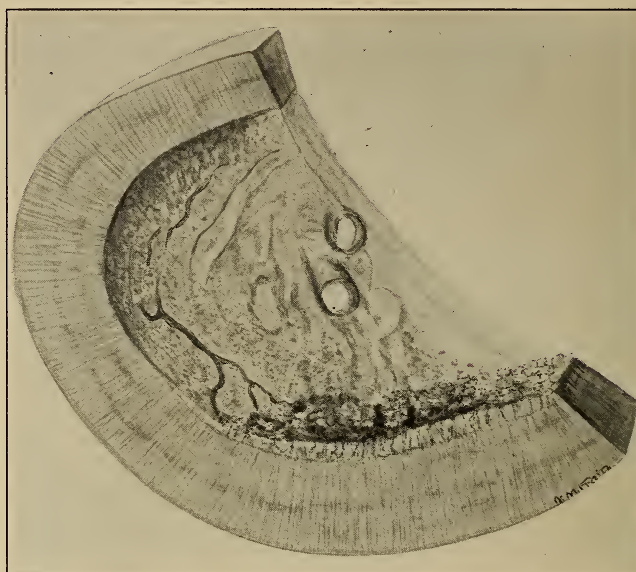


Fig. 149.—Diagrammatic drawing of a section of a tooth, showing injected lymphatic vessels in the pulp.

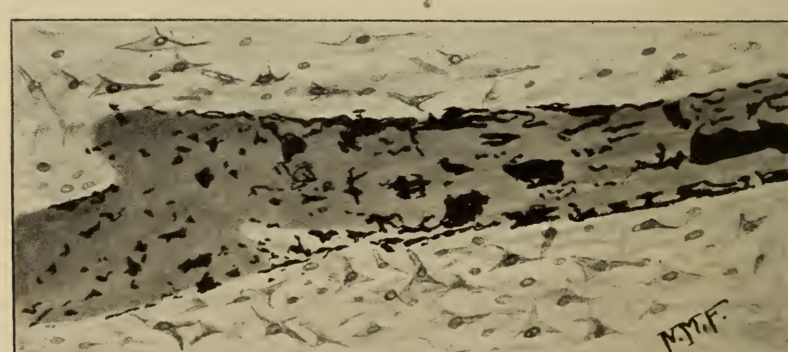


Fig. 150

brane (Fig. 164). For their course from this point see p. 195. In the body of the pulp independent lymph vessels are found and perivascular lymph sheath surrounding bloodvessels (Fig. 150).

The Nerves of the Dental Pulp.—Few subjects in connection with dental histology have received more attention than the distribution of the nerves of the dental pulp, especially in relation to the sensitiveness of the dentin.[1]

For fifteen years or more Dr. Howard Mummery has been doing work on the distribution of the nerves of the dental pulps. He has described nerve-end-cells lying between the odontoblasts at their pulpal end, from which neuro-fibrils extend through the layer of odontoblasts and enter the dentinal tubules with the fibers of Tomes. According to his description these cells form true sensory neurons the axon of which extend throughout the dentin in the dentinal tubules, their dendrons connecting with the terminal fibrils of the axons entering the pulp through the apical foramina He considers the odontoblasts as the builders of the dentin matrix, or at least the calcification of it, and the nerve-end-cells to perform the sensory functions formerly ascribed to the odontoblasts and their fibrils.

Support for almost any idea can be found in the literature, but many of the conditions described have been shown to be errors in microscopic interpretation, and many others have failed to receive support by reinvestigation. The most recent work in this country upon this subject was done fifteen or twenty years ago by Prof. Carl Huber, of Ann Arbor. The author has repeated some of his work, and has never seen any specimen that was contradictory to his statements. Usually three or four nerve trunks enter the dental pulp through the foramina. These contain from eight or ten to thirty or forty medullated nerve fibers. They pass occlusally through the central portion of the pulp, but almost immediately begin to give off branches, which pass toward the periphery, branching and anastomosing in their course. Most of the fibers lose their medullary sheath very soon after leaving the nerve trunk, proceeding as beaded fibers, made up of an axis cylinder with nuclei scattered along it. A bundle of such fibers, breaking up to be distributed to one horn of the pulp, is shown in Fig. 151. Other fibers retain their medullary sheath, following an independent course through the pulp tissue, until they reach the layer of Weil, where the sheath is lost and they join the plexus of beaded fibers lying in this position (Fig. 151). From the plexus

[1] Several investigators have described nerve fibers entering the dentinal tubules. The most complete and elaborate work is that of Howard Mummery. For which the student is referred to, Microscopic Anatomy of the Teeth. J. Howard Mummery, p. 211.

in the layer of Weil beaded fibers are given off, passing between and around the odontoblasts, forming a network around each cell, and even passing over on to the end of the cell between it and the dentin, but they have never been followed into the dentinal tubules. In no instance and by no method that he has employed, has Dr. Huber been able to demonstrate nerve fibers in the dentinal tubules.

The sensitiveness of the dentin, in view of these observations, is due to the presence of living fibrils, connected with living odontoblasts which are in physiologic connection with nerve fibers. It

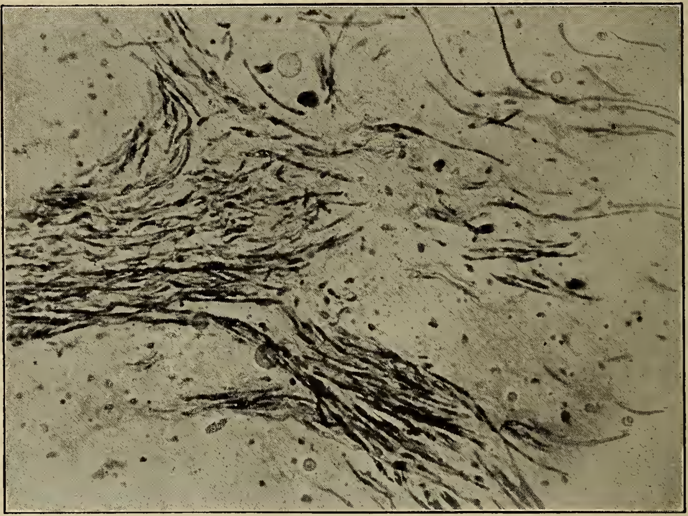


Fig. 151.—Nerve fibers in pulp from a human molar. (About 500 ×)

is interesting to note that this is the only instance in which a connective-tissue cell is intermediate between the outside world and the nerve fiber. In all other instances an epithelial cell is intermediate between the environment and the nervous system. The sensitiveness of the dentin is therefore due to the irritability of the cytoplasm of the fibril, transmitted through the continuity of cytoplasm to the odontoblasts and their reaction upon the surrounding nerve fibers. The irritation to the fibril may be either traumatic, chemical, or thermal. For instance, salt is sprinkled on exposed living dentin, and a sharp sensation of pain is the result. It may be supposed that chemical changes are set up in the cytoplasm of the fibril which excite changes in the cytoplasm of the odontoblasts.

These react upon the cytoplasm of the nerve fiber, and so are transmitted to the nerve center, being recognized, in consciousness, as a sensation of pain. In the same way traumatic irritation caused, for instance, by the cutting of dentin with a steel instrument sets up changes in the fibril in the same fashion. It is impossible to conceive of any vital activity of cytoplasm otherwise than as a form of chemical action or molecular or atomic movement of its substance.

Certain clinical facts are well explained by these structural facts. It is often noted in the preparation of cavities that the dentin is most sensitive at the dento-enamel junction. This would be expected when it is recalled that at the dento-enamel junction the dentinal tubules fork and the fibrils anastomose, so that an

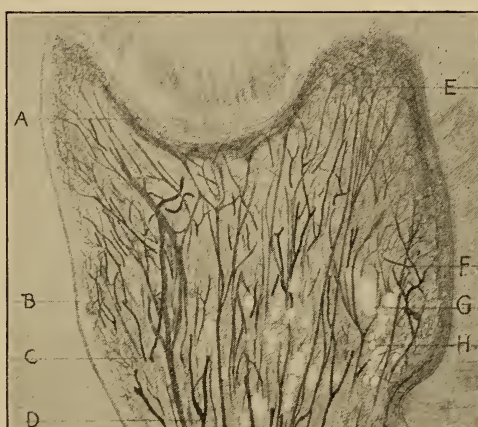


Fig. 152.—Röse's diagram of nerves and bloodvessels of the pulp.

irritation to a few fibrils is not simply transmitted to their odontoblasts and the nerve endings in contact with them, but to all the fibrils, and so to the nerves in contact with all of the odontoblasts. The presence of dilute acids render the cytoplasm of the fibrils much more irritable. The dentin in a carious condition is therefore much more sensitive than that in a sound or normal area. The sensitiveness of extremely hypersensitive dentin can often be greatly reduced, if not entirely overcome, by cleansing the cavity thoroughly, washing with tepid water, followed by a dilute alkali, drying and sealing for a few days, when it will be usually found that excavation can be carried out without excessive pain. The sealing must be perfect. If it is leaky the cavity will be more sensitive than ever at the end of the delay.

Teeth in which the size of the pulp chamber has been reduced by the formation of secondary dentin are usually much less sensitive. By this formation, as has been seen in the chapter on dentin, many of the tubules are cut off and many of the fibrils reach the pulp only by anastomosing with a few in the later formed dentin. The transmission to the nerves of the pulp is thus made more difficult and imperfect.

In all considerations of the sensitiveness of dentin, the purely subjective and hysterical symptoms must be carefully watched for. In many cases slight sensations are so magnified by fear and expectation as to be considered intolerable. In such cases the diversion of attention and the skilful use of suggestions are of more value when coupled with delicacy of manipulation and operative skill than any means of obtunding. In such cases, although the operator is positive that the sensations are slight, it will never do any good to tell the patient so, or to argue that what is being done cannot hurt. They must be made to believe fully that something has been done to destroy the sensitiveness, and then the attention must be concentrated upon something, while the excavation is lightly and skilfully performed. It makes very little difference what is done, but it must attract the attention in order to plant the belief that the sensitiveness has been removed, and then the attention must be diverted until the manipulation is completed.

The nerves of the pulp not only respond with sensations of pain from the irritation of the fibrils in the dentinal tubules, but because of their confinement in a calcified chamber and the semifluid nature of the tissue, they are very sensitive to pressure, either increased or decreased. The normal response to changes of temperature, as well as most of the pain in pathologic conditions of the pulp, are probably caused by changes of pressure, through disturbance of the blood circulation of the tissue. The nerves of the pulp control the walls of the arteries through the vasomotor reflexes, and also by trophic fibers control the functional activity of the odontoblasts in the formation of the dentin.

In a single tooth the irritation resulting from a carious cavity is found to cause the formation of dentin not simply in the region reached by the irritated fibrils, but upon the entire wall of the pulp chamber and apparently also in other teeth. It has seemed possible to the author that in some instances osmotic conditions might be a factor in the production of pain in the pulp, especially in the early stages of caries.

CHAPTER XIV.

THE LYMPHATICS OF THE DENTAL REGION.

GENERAL CONCEPTION OF THE LYMPHATIC CIRCULATION.

The student generally finds difficulty in getting any clear idea of the lymphatic circulation. It seems best, therefore, to make a most simple and elementary statement of this most important circulatory system as a basis for a study of the lymphatic vessels. Life at present can be understood only in terms of a single cell. Every living cell must be bathed in fluid from which the cytoplasm receives the material for its constructive processes and to which it gives up its waste products or the results of catabolism. Just as the single-celled protozoan floating in a pond of water, so each cell of every tissue of the body can be considered as bathed in a fluid—*the lymph.* The epithelium of all external and internal surfaces makes a bounding layer which prevents the loss of the fluid. If a slight cut or abrasion is made on the skin, removing the outer layer of dried cells and not breaking the blood capillaries, there will appear the exudation of a drop of yellowish fluid on the surface. This fluid immediately coagulates and prevents further loss until the continuity of the surface is restored. In this simple way we may demonstrate the presence of the intercellular fluid or lymph.

For the health and nourishment of the cells this fluid must be in circulation or the cells would be poisoned by their own products of catabolism. In a very general way the blood circulatory system may be said to be the means of bringing oxygen to the tissues and the lymph circulatory system the means of supplying the material for metabolism.

The fluid of the blood passes through the cells of the capillary walls into the intercellular and tissue spaces, and in that sense may be considered the source of the lymph. The passage of the blood plasma through the capillary walls is not simply a matter of transfusion or osmosis, but is a vital function of the cells of the capillary walls. The intercellular lymph is not the same as the plasma of the blood in the bloodvessels, for from it the cytoplasm of the tissue cells have taken up material and to it they have given products of metabolism.

The fluid from the intercellular and tissue spaces is collected by a system of vessels, *the lymphatic vessels,* and returned to the blood circulation through the thoracic duct emptying into the left subclavian vein. On the right a very short, lymphatic duct, not more than 10 to 12 mm. in length, empties into the right subclavian vein. Very frequently no right lymphatic duct exists, the jugular and subclavian trunks opening independently into the right subclavian vein.

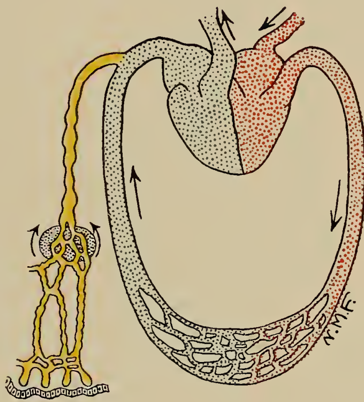
Formerly it was supposed that the smallest of the lymph vessels or lymph capillaries opened directly into the intercellular and tissue spaces, but it has become more and more evident that this is not correct but that the lymphatic vessels form a closed system opening only into the subclavian veins. The intercellular fluid passes into the lymph capillaries through their wall by a vital process. A diagram of the lymphatic vessels and their relation to the blood circulation is shown in Plate XII.

It is undoubtedly true that the blood capillaries also may take up fluid from the tissue as well as give up fluid to it and it is certain that they take up products of metabolism from the tissue cells. But as a beginning and elementary idea the statement may be made that the plasma of the blood passes out of the capillaries, bathes the cells, giving up material to them and receiving products from them, and is returned to the blood circulation through the lymphatic vessels.

In comparing the two systems in Plate XII several things can be noted: (1) The blood passes from the heart, through the arteries to the capillaries and back to the heart in the veins; and is a closed system all the way. The lymph is collected from the tissue spaces by the lymphatic capillaries, passes through collecting trunks to the glands, where it passes through the capillaries again and on to the blood circulation through the subclavian vein. (2) The blood circulation is the oxygen carrier, the lymphatic circulation the food and waste carrier. (3) The blood circulation is rapid, the lymph circulation slow.

Lymphatic Nodes or Glands.—Along the course of the lymphatic vessels are placed structures, lymphatic nodes or glands in which the fluid must come in contact with masses of active cells for the purpose of preventing infection carried in the current from reaching the blood circulation and so the entire body. For the structure of the lymph nodes and their relation to the lymphatic vessels the student is referred to text-books of histology and anatomy.

PLATE XII



General Scheme of the Lymphatic System.

PARTS OF THE LYMPHATIC SYSTEM.

To have a conception of this system, the fluid that circulates, the cells it carries, the vessels through which it goes, and the tissue or special structures through which it passes in its course, must be studied in their relation to each other.

1. Lymph.
2. Leukocytes (cells found in the lymph).
3. Lymph vessels.
4. Lymphatic glands (lymph nodes).

Lymph.—The lymph is a slightly viscous liquid, sometimes with slightly yellowish color, no or very slight odor, slightly alkaline reaction, and specific gravity of 1.012 to 1.022. Krause states that the entire quantity of lymph is equal to one-third of the body weight. Five and one-half liters have been collected from the thoracis duct from man in twenty-four hours. The quantity is dependent upon tissue activity.

From the most fundamental conception of it the lymph must be slightly different from the plasma of the blood. And its chemical composition must be variable. It is slightly less alkaline and contains less fibrin than the blood plasma.

Leukocytes.—The term leukocytes includes cells that are found in the blood, lymph, and connective tissues, and is synonymous with white blood corpuscles.

The leukocytes are soft cytoplasmic masses with no cell wall, nearly colorless, extensible, and of varying refraction. They are heavier than lymph or plasma and lighter than red corpuscles. They are viscous, adhering to a glass slide and sticking to the walls of vessels, resisting the current which carries them along, so that they accumulate when the current slackens.

They possess all the biological properties of primitive cells, mobility, sensibility, absorption, secretion and reproduction. Such important functions as the absorption of foreign matter and bacteria are dependent upon these primitive functions.

Leukocytes have been classified by their form, size, the character of the nucleus and the granules found in the cytoplasm.

Lymphatic Vessels.—Lymphatic vessels were discovered by the ancient Greeks and were known by Aristotle (384–322 B.C.), but the knowledge was lost and they were rediscovered by Nicholas Massa in 1532 A.D. In 1563 Eustachius discovered the thoracic duct.

It was formerly believed that the lymph in the intercellular spaces drained into the interfibrous spaces in the connective tissues, that these became lined with endothelial cells and that the lymph capillaries opened into them. It has been more and more apparent that the lymphatic vessels present a system closed at the periphery and opening into the subclavian vein at the opposite extremity. This does not in any way change the action of the system. The taking up of the lymph from the tissue spaces cannot be thought of as a simple process of filtration but as a vital function of the cells forming the closed ends of this terminal or collecting plexus of the lymphatic capillaries. The entire system of the lymph vessels may be more clearly understood if it is thought of as made up of the following parts: (1) The network of origin or terminal plexus of the lymphatic capillaries which take up the lymph from the tissues and organs. (2) A few vessels *collecting trunks* drain a comparatively large area of the collecting capillary network and carry the lymph from the network to the first lymphatic gland. (3) In the gland or node it again breaks up into capillaries, but leaves the gland through one vessel, the efferent vessel. (4) Larger and less numerous efferent ducts which carry the lymph from one node to another or from the last node to the venous system.

Fig. 153

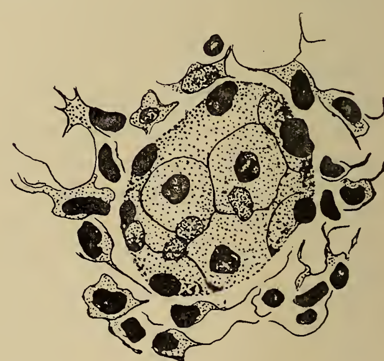


Fig. 154

Figs. 153 and 154.—Lymphatics in involution. Fig. 153, lymphatic vesicle in continuity with neighboring trunk; Fig. 154, isolated vesicle. (After Ranvier.)

The structure of the vessels is different in the different parts but may be described in general by saying that the capillaries and small collecting vessels are lined by a single layer of exceedingly delicate endothelial cells and the larger trunks show three layers similar to the walls of the veins but more delicate in structure (Figs. 153 and 154).

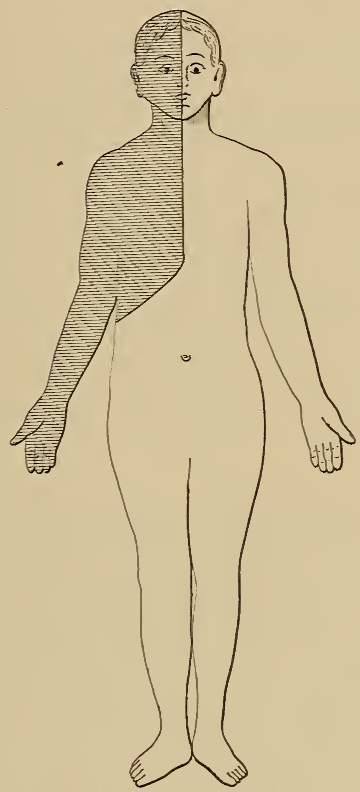


Fig. 155

As a general statement the network of origin is in the subepithelial connective tissue. The collecting and transporting trunks are found in the connective tissue and are either superficial or deep, as they are above or below the fascia. The superficial vessels are usually more highly developed.

The total capacity of the network of origin is very great, being equal to or greater than that of the veins, but the capacity is greatly reduced in the collecting and efferent ducts, so that the entire system is representative of a cone, with the base in the network of origin and the apex in the opening into the subclavian veins.

There are two entirely independent systems of the lymphatic vessels, one emptying into the right subclavian vein through the right lymphatic duct, draining the right side only as far as the level of the diaphragm, and the other into the left subclavian vein through the thoracic duct, draining all of the rest of the body. The area of the body drained by each system is represented in the diagram in Fig. 155.

The Network of Origin.—The delicate vessels which form the network of origin are often called the lymphatic capillaries. They resemble the blood capillaries only in that their walls are formed by a single layer of endothelial cells. They are of extremely variable form, depending upon the character of the tissue in which they are found. They form a very rich anastomosing network of very delicate vessels, some idea of the structure of which can be had from Figs. 156 and 157. A few very delicate vessels collect the lymph from this network and carry it to the collecting trunks. The capillaries are without valves but the collecting vessels are abundantly supplied with them (Fig. 154), which causes their characteristic beaded appearance. Stained with silver nitrate the cells are more easily outlined than those of the blood capillaries, showing cells 30 to 40 microns long. Their edges are wavy, forming lines like the sutures of the skull. Their nuclei are oval and project into the cavity of the vessel, especially when they are not distended. The diameter of these vessels may be from 30 to 60 microns, which is much greater than that of the blood capillaries.

The Collecting Trunks.—The walls of the collecting vessels are made up of three layers: (1) The endothelium. (2) A layer of involuntary muscle. (3) An adventitious layer of white elastic connective tissue. They are like the walls of the veins, but more delicate, less destructible and more resilient to pressure.

Lymphatic Glands or Lymph Nodes.—For the structure of the lymph nodes the student is referred to text-books of histology. They are by no means constant either in number, size or position. In order to understand the lymphatics of the dental region it is necessary to make a brief statement of the principal groups of the head and neck and the regions which they drain.

The Lymphatics of the Head and Neck.—The lymphatic glands of the head and neck may be described as arranged in six groups, forming a grandular collar or circle at the junction of the head and neck from which two vertical chains extend under the sterno-mastoid muscle and along the large bloodvessels and nerves extending to where the neck joins the thorax. These main vertical chains are flanked by lesser auxiliary chains (Fig. 158).

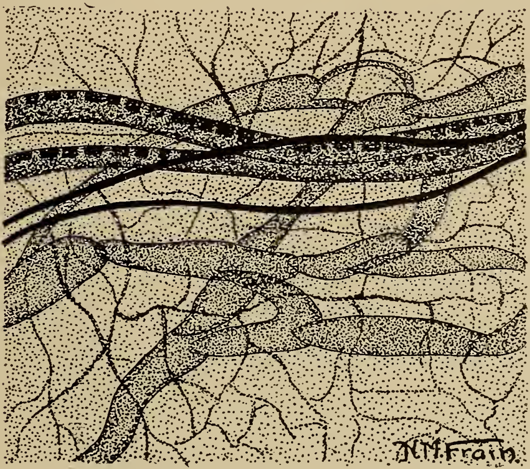


Fig. 156

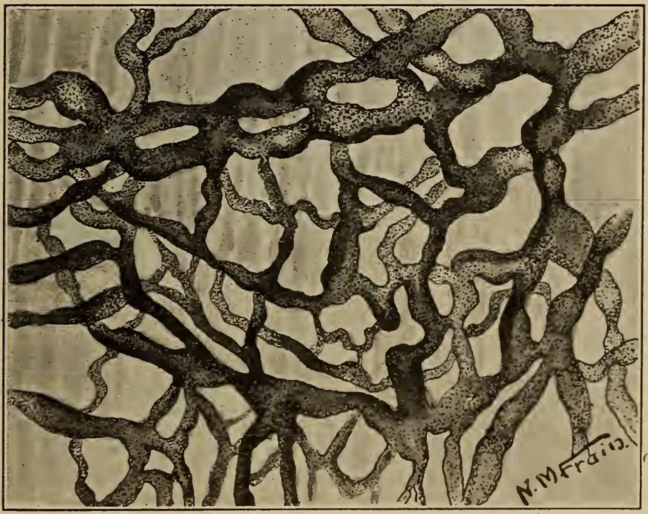


Fig. 157

The glandular collar is composed of (1) the *suboccipital group;* (2) the *mastoid group;* (3) the *parotid* and *subparotid group;* (4) the *submaxillary group;* (5) the *submental group;* (6) the *retropharyngeal group.*

1. The *suboccipital group* usually contains two glands. They receive efferents from the occipital portion of the scalp. Their efferents terminate in the highest glands of the substernomastoid group of the vertical chain.

Fig. 158

2. *The Mastoid Group.*—There are usually two, one behind the other, and are united by two or three trunks. They lie on the mastoid insertion of the mastoid muscle. They receive afferents from the temporary portion of the scalp, from the external surface of the

auricle, except the lobule, and the posterior surface of the external auditory meatus. Their efferents empty into the superior glands of the submastoid group after traversing the superior insertion of that muscle.

3. *The Parotid Group.*—This group is made up of (1) the subcutaneous glands, which are often absent; (2) the glands contained in the parotid space; (3) the subparotid glands.

The glands of the parotid space are situated on the external surface of the gland or in its external substance. The superficial ones are usually two or three in number. The deep ones are scattered through the entire substance of the gland and are usually grouped along the external jugular vein and the external carotid artery. One constantly occupies the lower part of the space and is attached close to the angle of the jaw in contact with the cervical fascia. They receive afferents from the external surface of the auricle and external auditory meatus, from the tympanum, from the skin of the templar and frontal region, the eyelid and root of the nose. They perhaps also receive vessels from the nasal fossa and the posterior part of the alveolar border of the superior maxilla. Their efferents empty into the substernomastoid group.

The subparotid glands are placed between the parotid and the pharynx in the lateropharyngeal and posterior subglandular space. They are in contact with the internal carotid and the internal jugular. They are the starting-point of the lateropharyngeal abscess (Quaine). They receive afferents from the nasal fossa, nasal pharynx and Eustachian tube. Their efferents pass to the glands of the deep cervical chain.

4. *Submaxillary Glands.*—These glands, three to six in number, are the most important from the dental standpoint. They form a chain stretching along the inferior border of the mandible from the insertion of the anterior belly of the digastric to the angle of the jaw. They are found in the junction of the cutaneous and bony surface of the submaxillary gland on which they rest. The largest and most constant of the chain is found at the point where the facial artery crosses the border of the mandible. They receive afferents from the nose, the cheek, the upper lip and external part of the lower lip, the anterior third of the lateral border of the tongue and almost the whole of the gums, alveolar process and teeth of both upper and lower arch. Their efferents descend on the cutaneous surface of the submaxillary gland, across the hyoid bone and terminate in the glands of the deep cervical chain, over the bifurcation

of the carotid artery or much deeper, where the omohyoid crosses the internal jugular vein.

5. *The Submental Glands.*—These glands are extremely variable in number and position. Usually one to four in number they are found in the triangle between the anterior bellies of the digastric muscle and the hyoid bone. They receive afferents from the chin, the central portion of the lower lip, the tip of the tongue and the anterior portion of the alveolar process and the lower incisor teeth. The latter is probably not constant.

6. *The Retropharyngeal Group.*—These glands are placed behind the pharynx at the junction of the posterior and lateral surfaces, at the apex of the lateral masses of the atlas. Usually two in number they are in relation with the posterior wall of the pharynx and the anterior surface of the rectus—capitis anticus major and externally with the constrictors of the pharynx. They are about two centimeters from the median line. They receive afferent vessels from the mucous membrane of the nasal fossæ and the cavities connected with it, the nasal pharynx, Eustachian tube and perhaps the tympanum. Their efferent vessels empty into the superior glands of the internal jugular chain.

Descending Cervical Chains.—These extend from the glandular collar through the neck to the thorax. The most important chain is the deep cervical chain, one on each side, under the sternomastoid muscle and in the subclavian triangle. The smaller are the external jugular chain, the two anterior cervical chains, superficial and deep, and the recurrent chain.

The deep cervical chain (Fig. 166) is one of the largest and most important relays in the body. It contains fifteen to thirty glands. It is made up of two groups: (1) the upper or substernomastoid group, and (2) the lower or subclavian triangular group. Only the first group will be considered.

Substernomastoid Glands.—1. External Glands: Behind and external to the internal jugular vein. Afferent vessels are received from the occipital and mastoid glands and from cutaneous lymphatics from the posterior part of the head and neck.

2. Internal Glands: Rest on the internal jugular or along its external border. At different points in the chain, glands of special importance are found; for instance: (*a*) Beneath the posterior belly of the digastric, the principal terminus for lymphatics from the tongue and gum about the lower teeth on the lingual. (*b*) Where the omohyoid crosses the internal jugular. Afferent vessels: These

glands form the second relay for lymphs from the (*a*) retropharyngeal and (*b*) parotid and subparotid.

3. Submaxillary.
4. Submental glands.
5. The superficial and deep anterior cervical chain and the recurrent chain. They receive direct afferents from: (*a*) the majority of the vessels from the tongue; (*b*) part of the nasal pharynx and larynx; (*c*) the vault of the palate and soft palate; (*d*) the cervical portion of the esophagus; (*e*) the nasal fossæ; (*f*) the larynx and trachea; (*g*) the thyroid body.

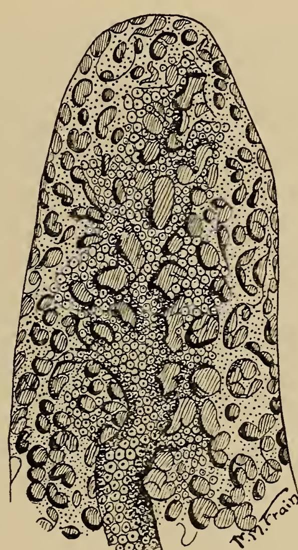


Fig. 159

The Network of Origin in the Dental Region.—The lymphatic network of origin is absolutely continuous over the whole of the face, eyelids, conjunctiva, lips and the mucous membrane of the lips, cheeks, gums and gingiva. Every papilla of the connective tissue under the epithelium contains such networks of vessels as are shown in Fig. 159 from papillæ of the hand. Exactly such structures can be shown from the mucous membrane of the gum and gingivæ. These capillaries empty into an exceedingly rich network of very delicate vessels in the subcutaneous and submucous layer, which is illustrated in Fig. 160. It is difficult for the elementary student to get any conception of the fineness, delicacy and intercommunicating anastomosis of this network. From this network a few collecting vessels lead to the afferent trunks going to the first glands. There is therefore a more or less definite drainage for a given area, though the network of origin is continuous.

Lymphatics of the Lips.—In the lips there are two networks: one in the subcutaneous layer of the outer surface and one in the submucous layer of the internal surface. These communicate freely at the border of the lips. Each network is drained by a few collecting trunks, which receive lymphatic vessels from the muscular

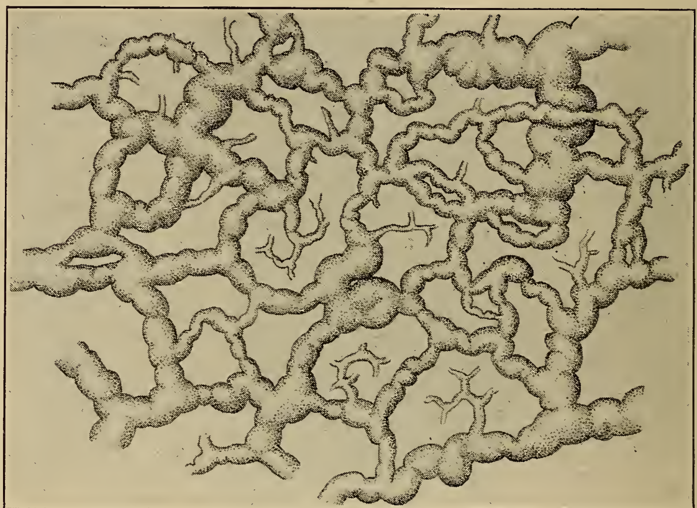


Fig. 160.—Lymphatic vessels of the collecting network. (Sappey.)

layers that are less developed. The subcutaneous collecting vessels of the lower lip, two to four in number on each side, frequently cross and anastomose at the median line. Those from the middle portion pass to the submental glands. Those from the region of the commissure reach the most anterior of the submaxillary glands (Fig. 161). The submucous collecting vessels, two or three on each side, pass obliquely downward and outward to the region of the facial artery and end in the submaxillary glands. They do not cross or anastomose at the median line. There are two submucous and two or three subcutaneous collecting vessels in the upper lip. They all pass obliquely downward and outward, usually to the middle gland of the submaxillary chain. One of these may enter the most external of the collecting trunk from the lower lip.

Lymphatics of the Mucous Membrane of the Mouth and Gums.—In the mucous membrane of the mouth and gums the network of origin forms an exceedingly close network.

From the outer surface of the mandible the collecting vessels form a wreath of interlacing vessels at the reflection of the mucous membrane from the bone to the cheek. The vessels increase in size as they pass distally and finally penetrate the cheek and end in the submaxillary glands, especially the last one.

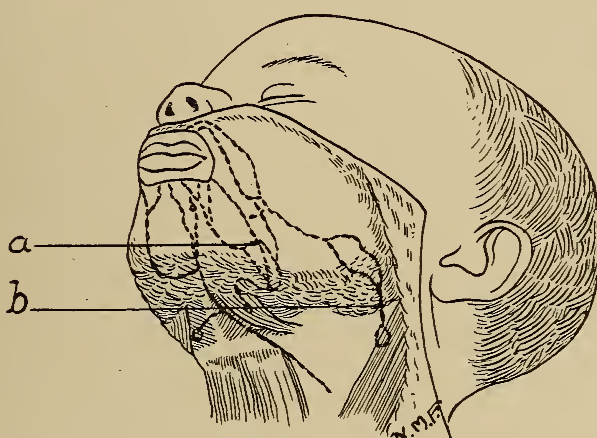


Fig. 161

From the inner surface of the mandible a similar wreath of collecting vessels is formed at the reflection of the tissue from the bone to the floor of the mouth and tongue. From the anterior part, lingual to the incisors, the vessels pass, with those from the tip of the tongue to the submental glands. From the lateral portion they unite with lymphatics from the anterior part of the lateral surface of the tongue and pass to the glands of the submaxillary chain. From the region of the second and third molars they probably join the lymphatics from lateral portions of the base of the tongue in the region of the tonsil and pass to the large gland of the deep cervical chain, placed under the posterior belly of the digastric.

Outer Surface of the Maxilla.—From the outer surface of the upper arch the collecting vessels pass to a wreath of large vessels at the reflection from the bone to the cheek. These increase in size as they extend distally. At the level of the molars they pierce the cheek, join the facial artery and terminate in the posterior glands of the submaxillary chain (Fig. 162). On the lingual the collecting vessels first pass obliquely backward and toward the median line of

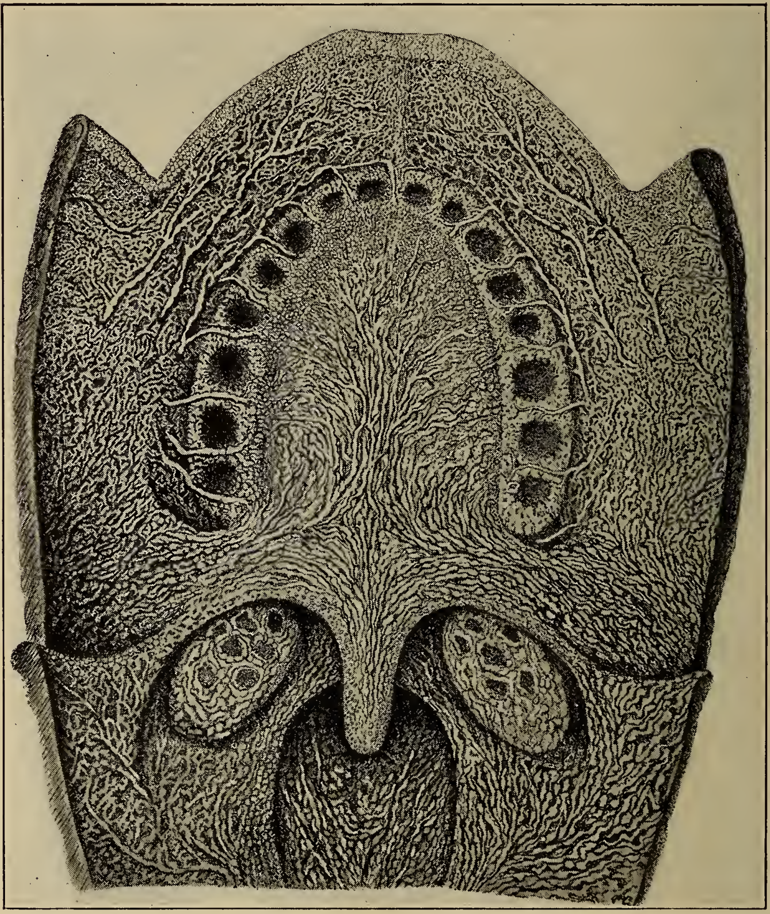


Fig. 162.—Lymphatic vessels of the palate. (After Sappey.)

the palate, then backward and upward at the junction of the hard and soft palates. They pass in front of the anterior pillar of the fauces, pierce the superior constrictor of the pharynx and end in the large gland of the deep cervical chain under the posterior belly of the digastric.

Lymphatics of the Peridental Membrane.—The lymphatic capillaries in the papillæ under the epithelium on the labial or buccal and lingual surfaces of the gingivæ pass to the collecting network in the submucous connective tissue outside the periosteum on the surface of the alveolar process (Fig. 162). The lymphatic capillaries from the papillæ under the epithelium lining the gingival space are col-

Fig. 163.—Unstained section, showing lymph capillaries of the tooth side of the gingivæ and their drainage through the ligamentum circulare to the peridental membrane.

lected in very fine vessels which pierce the ligamentum circularæ very close to the surface of the cementum and extend in the interfibrous tissue of the peridental membrane accompanying the blood-vessels (Fig. 163). At the level of the apex of the root they receive lymphatics coming from the dental pulp (Fig. 164) and pass through the cancellous spaces of the bone to the inferior dental canal in the

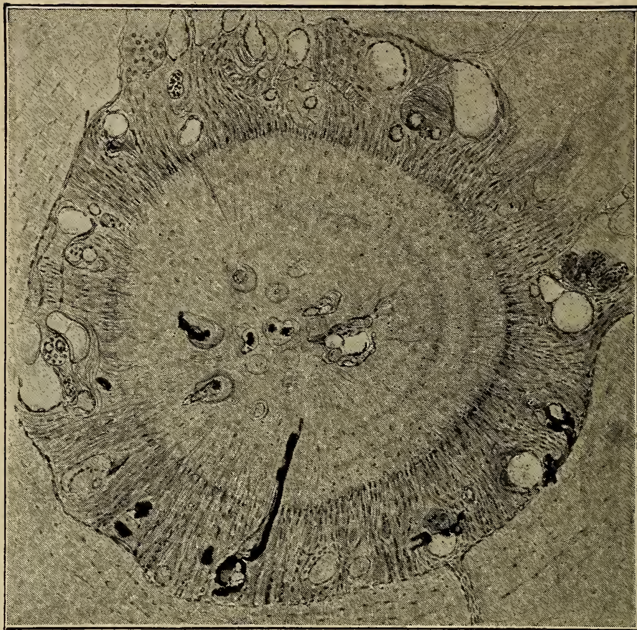


Fig. 164.—Transverse section just at the apex of the root, showing injected lymphatic vessels in the peridental membrane and in the canals passing to the pulp (oc., 2; obj., 16 mm.; reduced about one-third).

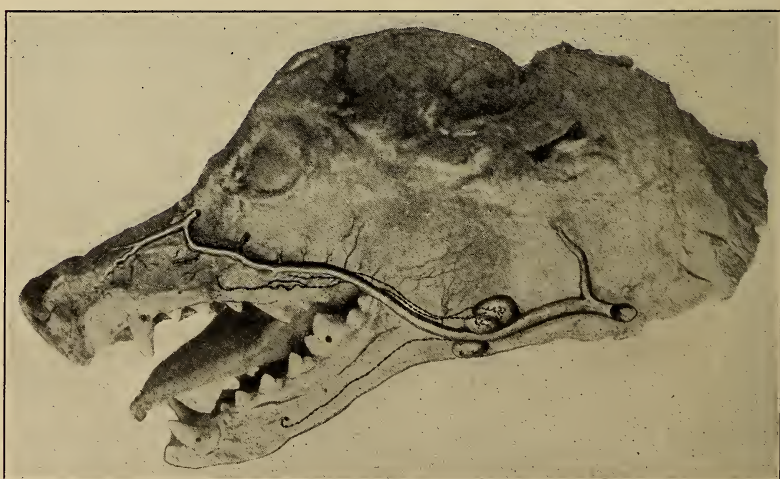


Fig. 165.—Dog's head, showing lymphatic glands injected from dental pulp.

lower and the infraorbital canal in the upper. They emerge on the surface of the bone at the mental foramin, or the infraorbital foramen and end in the posterior or middle glands of the submaxillary chain, following the course of the facial artery (Fig. 165). A great amount of work remains to be done on the drainage of the teeth in different regions. Little or nothing is known of the course of the vessels from the upper incisors, lower incisors and second and third molars. Lymphatics from the lower incisors may pass to the submental glands. Those from the upper incisors probably reach the surface of the bone below the level of the floor of the nose and join the vessel coming from the infraorbital canal, though it is possible that some of them join vessels in the floor of the nose. It is quite probable that lymphatics from the second and third molars pass to the glands of the parotid group.

Lymphatics of the Dental Pulp.—For many years the dental pulp was said to be devoid of lymphatics and all attempts to inject vessels in the dental pulp failed. In 1909 Schweitzer reported successful injections of the dental pulp, and in 1914 Dr. Kaethe Dewey and the author repeated Schweitzer's results and succeeded in injecting lymph capillaries of the submaxillary lymph glands in the dog by injections into the dental pulp and followed the course of the vessels continuously from the pulp to the glands (Fig. 165). There is much work to be done in this field before our knowledge will be at all complete regarding both the perivascular lymph sheath and the independent lymph vessels. The vessels begin at the surface of the pulp and follow the course of the bloodvessels to the apical foramina, where they join the lymphatics of the peridental membrane. Their course from this point has already been followed.

Lymphatics of the Tongue.[1]—The lymphatics of the tongue are very highly developed and have been thoroughly studied. There are two networks of origin: one superficial in the mucous membrane and one deep in the muscular body of the tongue. Their efferent vessels unite in the submucosa.

The collecting trunks are divided into four groups: (1) Anterior apical. (2) Lateral marginal. (3) Posterior or basal. (4) Median or central.

1. *Anterior Apical Trunks.*—These vessels, two on each side, run along the frenum to the posterior surface of the mandible. Here they separate (Fig. 166): (1) One runs downward and backward

[1] See page 270, The Lymphatics by G. Delamere, P. Poirer and B. Cuneo. Edited by Cecil H. Leaf.

between the geniohyoglossus and the mylohyoid crosses the great cornu of the hyoid bone behind the anterior belly of the digastric and along the external border of the omohyoid to the gland of the deep cervical chain where this muscle crosses the internal jugular vein. (The general statement is that the more anterior the origin in the tongue the lower the gland in the deep cervical chain to which it goes.) (2) The second trunk passes to the submental gland.

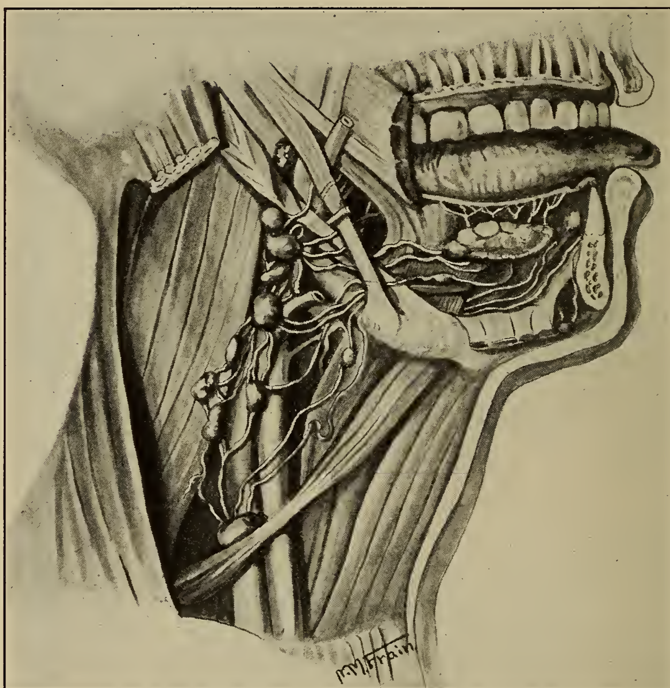


Fig. 166

2. *The Marginal Trunks.*—These vessels collect from all the mucous membrane from the tip of the tongue to the V-shaped groove on the dorsal surface. They are eight to twelve in number: (1) One group, the external (three or four), pierce the mylohyoid and pass around the inferior border of the mandible to the glands of the submaxillary chain. (2) The internal (five or six). These vessels run downward and backward on the muscles of the tongue and all end in glands of the deep cervical chain.

3. *Basal Trunks.*—These vessels (seven or eight) arise from the region of the circumvallate papillæ and are the largest and

most important vessels of the tongue. They form a medial and lateral group and all terminate in the large gland of the deep cervical under the posterior belly of the digastric.

4. *The Central Trunks.*—These vessels arise from the middle part of the dorsal network of the body of the tongue. Instead of running outward they descend in the middle line between the two genio-hyoglossi and end in the glands of the deep cervical chain.

CHAPTER XV.

INTERCELLULAR SUBSTANCES.

During the last hundred years, knowledge of living things and all thought of their structure and function has entirely changed. The cell theory has abundantly established that the cell is the structural and functional unit of all living objects, both plant and animal, and that all manifestations of life are accomplished by the chemical activity of the substance of the cell, which Huxley long ago designated as "the physical basis of life." From a consideration of the physical properties of cytoplasm, nothing is more apparent than that the production of a highly organized body out of it alone would be impossible. If the human body were composed entirely of cytoplasm it would be a shapeless lump of jelly. It is only by the production of material which has physical properties of strength and rigidity through the activity of the cytoplasm that the shape and function of a highly organized creature is possible. This is accomplished through the metabolism of the cytoplasm more or less analogous to the building up of a secretion by the cells of a gland, though there is no intention to suggest any direct comparison between the two. In other words, all tissues are made up of cells and intercellular substance, and the vital characteristics are given to the tissue by the cells, the physical characteristics by the intercellular substance. These intercellular or extracellular materials possess none of the vital manifestations, and are entirely dependent upon the cells for their formation and maintenance. There is apparently a constant reaction between the cell and the formed material which constitutes the intercellular substance, for even the most highly specialized of intercellular substances represented by the dentin matrix changes in its properties if the cells are removed. If the cells in the bone matrix are killed, that portion of the tissue becomes necrosed bone and is as much a piece of foreign matter as if a piece of bone toothbrush handle had been shot into the body. The fibers of fibrous tissue have no ability to grow, to attach themselves to any surface, or even to maintain their present form without the presence of living cells or fibroblasts.

There has been a great deal of discussion as to the method of formation of intercellular substances by the cells, and the nature of the reaction occurring between the cell and the formed material after it has been produced. In several intercellular substances the material passes through changes both of physical and of chemical character, but these are carried out by reaction with materials formed by the metabolism of the cell, for if the cells are removed the formed material will not go through any such changes. The intercellular substances, therefore, while they are chemically extremely complex, belong to the simplest classes of protein molecules, and have no such complexity of atomic movement, producing conditions of recurrent unsatisfied affinity, without which no idea of the metabolism of living cytoplasm can be obtained. Chemically, living cytoplasm may be roughly viewed as constantly undergoing chemical changes which are almost infinitely complex, and by means of which simpler substances are acted upon and built into its own molecule. Complex combinations are thrown off as products of its metabolism, and simpler substances are formed as decomposition products, or waste materials. Dr. Brooks often used to say in his lectures that the most striking characteristic of living things was their ability to react upon their environment in such a way as to become better and better suited to it. When living cytoplasm, which is soft and without the physical properties of strength and rigidity, requires protection from physical influences, substances possessing these qualities are produced by it. Intercellular substances therefore were apparently formed by the cytoplasm in response to physical conditions of its environment, and are one of the phases of adaptation.

In the higher forms of animal life the class of tissues which have produced these formed materials, for the purpose of support, rigidity, and connection, are called the connective or supporting tissue. The formed materials are of two classes—those which are to connect associated and dependent parts, and those which give rigidity and protection. The fibrous tissues are of the first class, and are made up of materials possessing strength and elasticity. The bone and cartilage belong to the second class, and give strength and rigidity. The first sustain pulling stress, the latter shearing or bending stress, though both possess a certain amount of each.

Adaptability and the greatest range of variation are most striking characteristics of connective tissue which develop and change to meet all kinds of requirements of both mechanical and physical environment to which they are subjected. These variations are produced by the production of increased amount of the intercellular material, its destruction, or the change of its character, under the influence of the cells of the tissue. No tissue responds more quickly to the demands made upon it by development or environment. When the muscles grow larger and stronger by development, the tendons and the bones to which they are attached change as quickly and in proportion. From the appearance of the skeleton the experienced anatomist can picture very accurately the muscular development of the individual to whom it belonged.

The cell wall of plants may be used as one of the simplest examples of supporting tissue. In this case each cell, in addition to its other

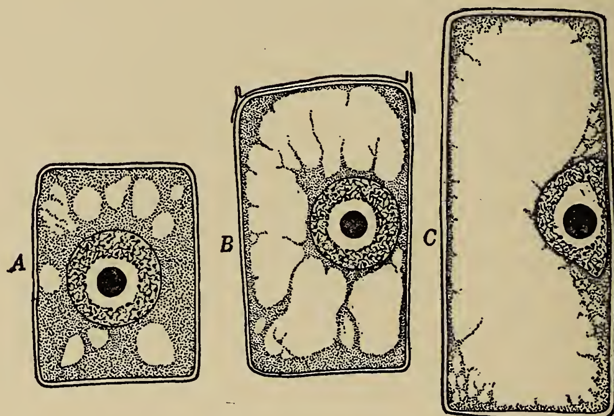


Fig. 167.—Cells from the growing tip of a chestnut seedling. (Dahlgren and Hepner.)

functions, produces its own supporting substance. These may be observed in the cells of a growing root tip. Plant an onion, by selecting one larger than a small glass, fill the glass with water, and place the bulb on it. If this is placed in a sunny window, in a few hours little rootlets will be seen stretching down into the water. The rootlets of a sprouting chestnut also make very good material (Fig. 167). If these are embedded in paraffin, the development of the cells and the formation of their supporting walls can be observed. The young cells near the tip will be found to be a mass of granular cytoplasm, with a large nucleus in the center, and a thin wall of cellulose which is the cell organ of support. As the cell increases in size, vacuoles appear in the cytoplasm which become larger and larger. These vacuoles are filled with watery fluid which is not a part of the cytoplasm. If the cell remained a solid mass of cytoplasm, an enormous amount of food material would be required, which would be out of all proportion to the work which the cell is to perform. The vacuoles increase in size with the growth of the cell until there is a rim of cytoplasm in contact with the cell wall, and a central mass of cytoplasm surrounding the nucleus and connected with that at the periphery by fine threads. In still further growth these threads are broken, the nucleus is pushed to one side, and the whole central portion becomes one huge vacuole. There is now a cell wall, with a layer of cytoplasm covering its inner surface, which is kept in reaction with the nucleus by streaming around and around. This flowing of the cytoplasm in plant cells may be easily observed in the delicate stamen hairs of the ordinary Spiderwort, or in the cells of the water plants Chara or Nitella, which are easily found in most ponds. In this example it is seen that the cytoplasm remains in contact with the formed material which it produces for support, and that it is only sufficient in amount to form and maintain this material.

In general histology it has already been noted that the cells of connective tissue are very similar, and that the tissues differ chiefly in the character and arrangement of the intercellular substances. It has also been emphasized that the connective tissues all originate from a common form of embryonal connective tissue, or mesenchyme, and change from one form to another in development. These mutations of the connective tissues are their most striking characteristic, and must be clearly grasped if the bone, as an organ of support, is to be understood. For instance, embryonal connective tissue is transformed into fibrous tissue; fibrous tissue becomes arranged in a definite membrane, and is transformed into cartilage, which is again removed and transformed into bone. All these changes take place to meet the requirement of mechanical conditions and environment.

If the subcutaneous tissue of an embryo be examined in sections (Figs. 168 to 183) the cells will be found to be irregular masses of cytoplasm with a nucleus in the central portion, and fine projections stretching out in all directions through an almost structureless intercellular substance. The fine projections of the cytoplasm meet those of the adjoining cells and form a network holding everything together. Because of the nature of cytoplasm, however, these possess very little strength, and very soon fine thread-like fibers are found appearing in the intercellular substance in contact with cells. These unite with each other, forming continuous fibers,

Fig. 168.—Embryonal connective tissue in an early stage of development, showing the cellular elements embedded in the ground substance. (Black.)

Fig. 169.—The same, a little more developed, showing the cellular elements lengthening in a common direction. (Black.)

Fig. 170.—The cells developed in spindle forms, fibroblasts with long filaments extending from either end. (Black.)

Fig. 171.—The developed white fibrous tissue. (Black.)

Fig. 172.—Older white fibrous tissue, in which the cells are no longer seen, and showing the wave-like course of the fibers. (Black.)

and very soon a strong network is produced which is entirely dependent upon the cytoplasm of the cell which has formed and maintains it. If this tissue is now subjected to pressure and strain, the cells become flattened out and squeezed between the bundles of fibers, which take on parallel directions, and so a tendon is

Fig. 173.—Coarse white fibers, made up of bundles of the fine fibers, and showing the mode of division by splitting off of a portion of the fibers of the bundle. (Black.)

Fig. 174.—Coarse fiber breaking up into fine fibers. (Black.)

Fig. 175.—Cross-sections of coarse fibers, showing some of their various forms. (Black.)

Fig. 176.—Reticular or elastic fibers, showing the mode of division and the multipolar, or irregular, star forms of the cells at the divisions. (Black.)

Fig. 177. — Cross-sections of the reticular fibers, showing some of their forms. (Black.)

formed. A tendon must be considered as a highly specialized form of connective tissue, arranged to supply tensile strength. The degree of specialization of the tissue is judged by the extent to

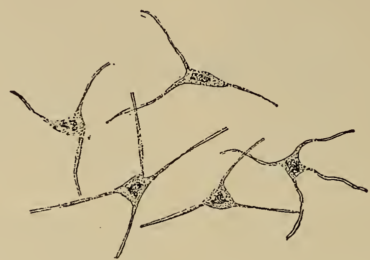


FIG. 178.—Connective-tissue cells from which reticular fibers are developed. (Black.)

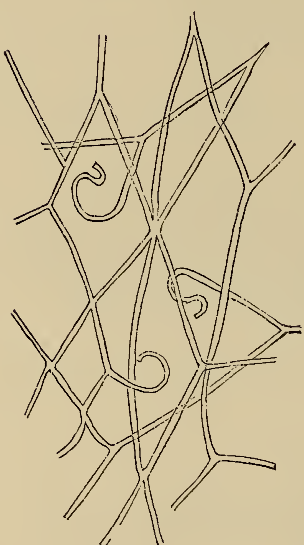


FIG. 179.—Network of elastic fibers from the point of reflection of the mucous membrane of the lip from the gums. (Black.)

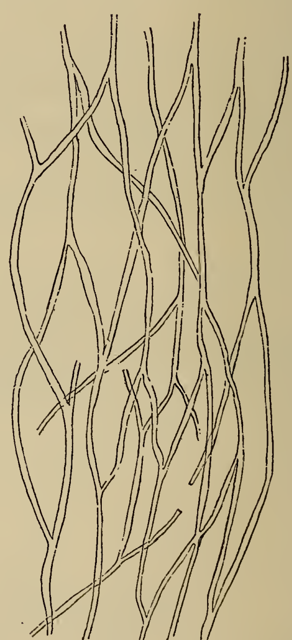


FIG. 180.—Network of elastic fibers teased out from elastic tendon, and showing the usual mode of division. (Black.)

which its characteristic features are developed, either in quantity or quality. In the tendon the fine, strong fibers have been gathered into bundles; a round nucleus would occupy too much space.

It has therefore become elongated and more or less rod-shaped, and the cytoplasm has been squeezed out into thin leaf-like projections between the bundles. Each cell is in contact with several fibers, and each fiber in contact with the cytoplasm of cells which have produced them.

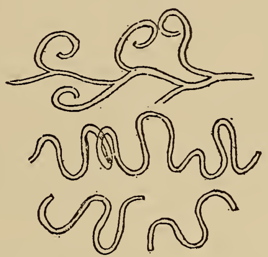


FIG. 181.—Elastic fibers, showing their disposition to curl up when cut or broken. (Black.)

It must be supposed that there is a constant reaction between the substance of the formed material and materials produced by the metabolism of the cytoplasm. In pathologic conditions the metabolism of the cytoplasm is disturbed, and there is a consequent change in the quality of the fibers. So in some pathologic conditions a relaxation and loss of tone is found in tendons and ligaments. In inflammations of the gingivæ the fibers become relaxed and stretched, so that the gingivæ are everted, but return to their normal condition when the pathologic condition has subsided, and the cells regain their normal metabolism.

FIG. 182.—Cross-sections of elastic fibers, showing their forms as seen in a group passing between coarse white fibers. (Black.)

FIG. 183.—Tissue of the dental pulp, in which the development of the cells is not followed by any considerable formation of fibers. (Black.)

To sum up what has been said, it is apparent that both phylogenetically and ontogenetically, intercellular substances have been produced and are maintained by cells in response to mechanical influences and to meet mechanical conditions. In all higher animals certain tissues, the connective tissues, have been set apart for this purpose, and the cells have been specialized to respond to mechanical stimuli and develop an intercellular substance adapted to the condition. This makes the supposition necessary that an embryonal connective-tissue cell may develop into any specialized form and that the kind of cell into which it develops will be determined by the character of mechanical stimuli which it receives. Just as the epithelial cells have been specialized to respond to the environments of light stimuli, vibration of the air, pressure, and chemical action which connect the organism with its environment, connective-tissue cells have been specialized to respond to mechanical stimuli, by the production of formed materials adapted to the mechanical conditions. These conceptions are fundamental to an understanding of bone structure and growth, and the mutations of connective tissue in general.

In no branch of histology is a clear conception of intercellular substances and the relation of cells to them as important as in the study of the teeth and their associated structures. Caries cannot be understood unless these fundamental ideas have been appreciated, and many statements in dental literature would never have appeared if the nature of intercellular substance and the relation of cytoplasm to it had been understood.

CHAPTER XVI.

BONE.

Definition.—Bone may be defined as a connective tissue whose intercellular substance is calcified and arranged in layers around nutrient canals or spaces. The cells are placed in cavities, lacunæ, between the layers, and receive their nourishment through very minute channels, canaliculi, which radiate from them and penetrate the layers.

STRUCTURAL ELEMENTS.

The structural elements of bone are:

1. Bone matrix, or intercellular substance, which is always arranged in layers or lamellæ.

Fig. 184.—From a section through the bone of a roebuck. The lacunæ are seen from above, and are filled with coloring matter. In places small dots are visible, which represent the cross-sections of bone canaliculi. (850 ×) (Szymonowicz.)

2. The bone cells or bone corpuscles which are embedded in the matrix between its layers.

3. Lacunæ, or the spaces in which the cells are found.

4. Canaliculi, or the channels through the matrix by which the embedded cells receive nourishment.

Bone Matrix.—The bone matrix is composed of a dense organic basis of ultimately fibrous character which yields gelatin upon

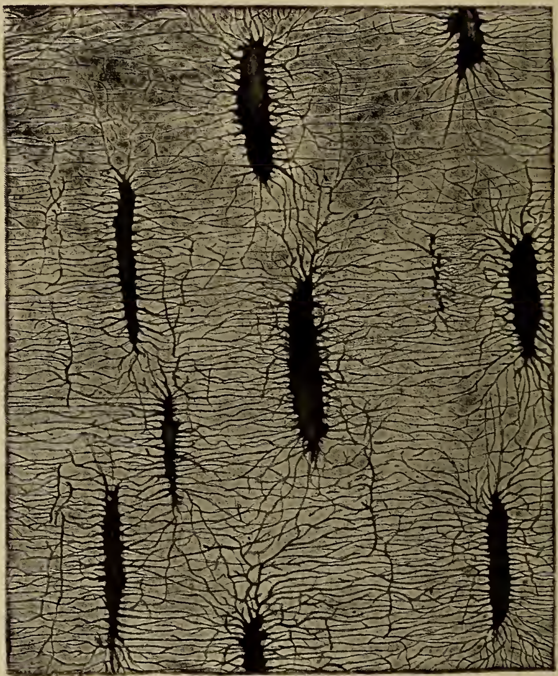


FIG. 185.—From a section through the bone of a roebuck. The lacunæ are seen from the side. (850 ×) (Szymonowicz.)

boiling with water. With this inorganic salts are combined in a weak chemical union, forming the hard substance of bone. By treatment with acids the inorganic salts can be removed, leaving the organic basis which retains the form of the tissue. In this condition the rigidity of the bone is destroyed. On the other hand, by calcining at red heat the organic basis can be removed, leaving the inorganic substances which retain the form of the tissue. In formation the organic basis is apparently formed first, and then the salts of lime are combined with it, through the agency of the formative cells or osteoblasts.

Bone Corpuscles.—Bone corpuscles are the cells lying in the lacunæ. Each cell contains a single well-defined nucleus, lying in the centre of a granular cytoplasm. The cell apparently completely occupies the lacunæ, and from the central mass fine projections of cytoplasm extend through the canaliculi, which bring the bone corpuscles in intimate relation with certain areas of bone matrix. The processes of one cell anastomose with those of its neighbors through the canaliculi, so that there is a continuous network of living cytoplasm throughout the matrix.

Lacunæ.—The lacunæ are flat, oval spaces about 20 microns long, 10 microns wide, and 5 or 6 microns thick. Their shape, therefore, in sections depends upon the way in which they are cut, as illustrated in Figs. 184 and 185. When cut lengthwise they would appear as about 20 microns long and 6 wide in profile, or as about 20 microns long and 10 wide when seen from above.

Canaliculi.—These radiate from the lacunæ in all directions, opening into them by larger channels which branch and divide, becoming smaller as they pass farther into the matrix. They anastomose freely with those from adjoining lacunæ.

THE VARIETIES OF BONE.

There are three varieties of bone differing in the arrangement of these structural elements. These are subperiosteal, Haversian system, and cancellous bone.

Subperiosteal Bone.—This form of bone must be regarded as primarily a formative arrangement and more or less transitory, in which the layers are arranged parallel with the surface, and under a formative membrane. It contains canals (Volkmann's canals) with bloodvessels (Fig. 186), connective tissue, etc. These penetrate the layers which are never arranged concentrically around them. It is always thin, that is, composed of comparatively few layers, and when a considerable thickness is formed it is cut out from within by absorptions beginning in the canals, and bone is rebuilt with layers arranged concentrically around the channels formed. In this way subperiosteal bone is converted into the second form.

Haversian System Bone.—In this variety the lamellæ are arranged concentrically around canals which contain bloodvessels, nerves, and embryonal connective tissue, and from which the cells in the lacunæ are nourished (Fig. 187). These canals are, in general, parallel with the surface or the long axis of the bone and anastomose with each other. A canal with the layers arranged around it constitute a Haversian system. Between the Haversian systems are remains of the subperiosteal layers (interstitial lamellæ) that were left by the absorption, and for that reason have been called fundamental lamellæ. They have also been called ground lamellæ. Haversian system bone is often called compact bone, and makes up

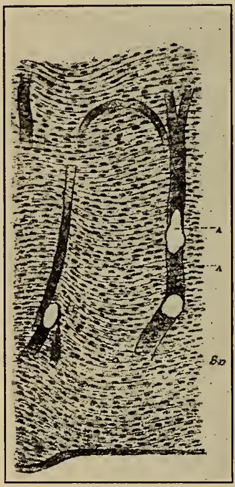


Fig. 186.—Subperiosteal bone, showing Volkmann's canals.

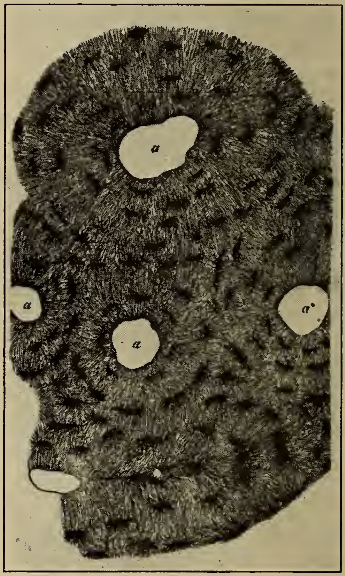


Fig. 187.—Haversian system bone: *a*, Haversian canals.

the greater part of the shafts of the long bone, and the plates of the flat ones. It is never allowed to become greater in thickness than is necessary for strength, and when sufficient thickness has been formed, the deeper part is cut out by absorptions in the Haversian canals, converting them into large irregular spaces. The formation of a few layers around these spaces transforms the second type into the third or cancellous bone.

Cancellous Bone.—In this variety the lamellæ are arranged in delicate plates surrounding large, irregular nutrient or marrow spaces. These are filled by embryonal connective tissue and contain bloodvessels and nerves. The plates of cancellous bone are not arranged at haphazard, as might be supposed from a casual observer of sections, but are disposed in definite arrangement, which is determined by the directions of stress on the compact bone which they support. (See illustrations in Chapter XXVII.) They are not permanent and unchanging, but are continually being rebuilt in new directions, in response to the mechanical conditions to which the bone as a supporting organ is subjected.

THE ARRANGEMENT OF BONE.

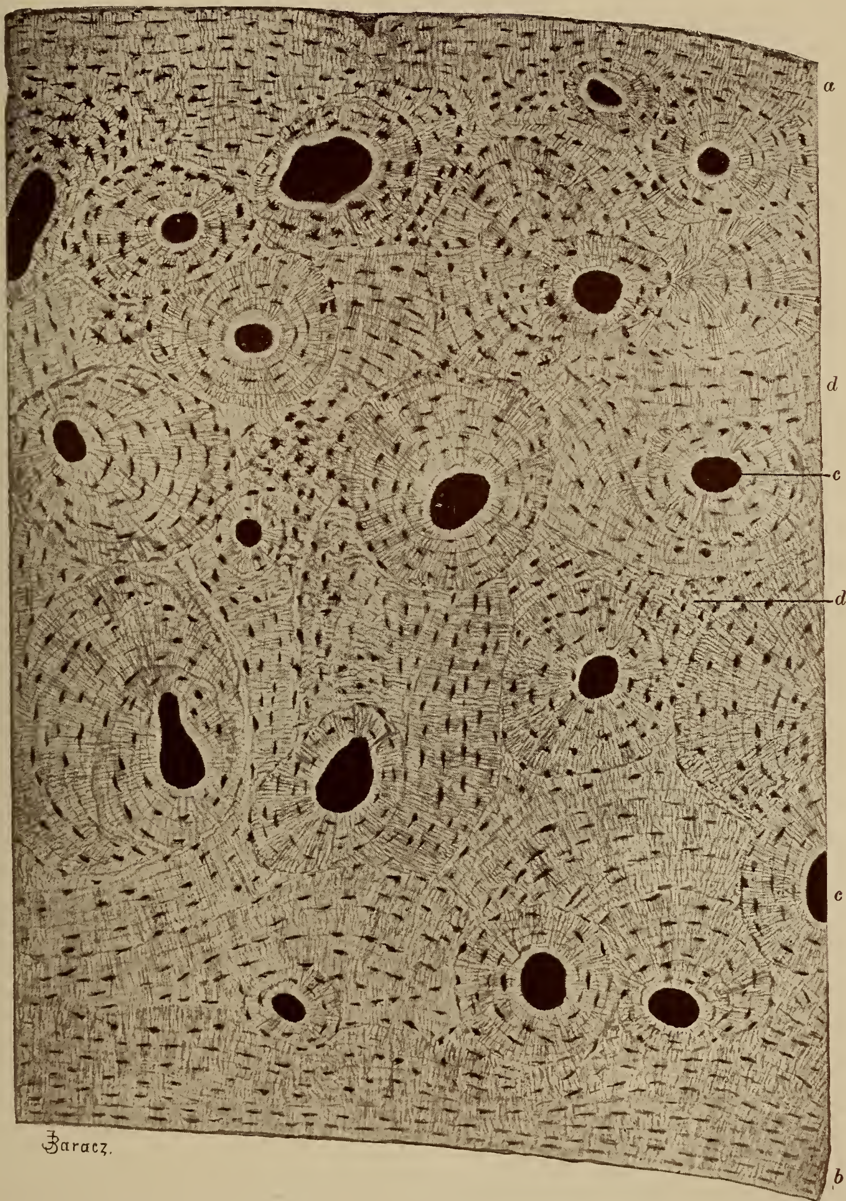
Compact Bone.—A knowledge of the structural elements of bone can best be obtained by the study of sections ground from the shaft of a long bone. An old dry bone should be sawed across, near the middle of the shaft, in two places, so as to cut out a ring about a quarter of an inch thick. Then saw the ring through in two places with an arc of about a quarter of an inch on the outer surface. From this two slices should be sawed out, one transverse to the long axis of the bone, the other parallel with it. These are ground to not more than 8 or 10 microns in thickness and mounted in hard balsam. From a study of these two the arrangement of the lamellæ, and the shape and character of the lacunæ can be made out. Upon the outer surface of the transverse section will be found a larger or a smaller number of layers of subperiosteal bone which encircle the shaft, and consequently are called the circumferential lamellæ. The number of these layers will depend upon the position from which the section is taken, and the age of the bone. If the bone is increasing in circumference at the point from which the section is cut, there will be a considerable number of layers, and they will be easily seen. If the bone has been growing smaller in circumference at the point, there will be very little of subperiosteal bone, and it will be comparatively hard to recognize. The greatest part of the section will be made up of Haversian systems, in which from two or three to five or six layers are arranged around an Haversian canal. The lacunæ appear as irregularly oval spaces about 5 or 6 microns across and 15 to 20 microns in length. From them a great many minute canals radiate through the matrix, both toward the Haversian canal and away from it. The character of these canaliculi can only be appreciated by seeing them. They are filled in life by projections of the protoplasm of the bone corpuscles. They are suggestive of the rootlets of plants running through the soil, and as in that case the rootlets are absorbing material from the soil and reacting with it, in this case the protoplasmic contents of the canaliculi are reacting with the matrix, maintaining its quality. The portion of matrix through which the canaliculi from one lacunæ extend belongs to the bone corpuscles which occupies the lacunæ, as will be seen later. These cells have been enclosed in the matrix which they have formed. Between the Haversian systems will be found a few layers of interstitial or fundamental lamellæ. They are the remains of layers which were formed under the periosteum and were not entirely destroyed when it was replaced by Haversian systems (Plate XIII). The amount of interstitial lamellæ varies greatly in different specimens, as will be seen by comparing figures.

The Haversian canals anastomose with each other; this will be seen in many specimens. Many Haversian systems will be found imperfect in form, as, for instance, those shown in Plate XIII. This means that after these systems were completed, absorptions occurred in a neighboring canal which attacked the layers of the system, and later a new system was formed in this space by the deposit of concentric lamellæ. While bone is thought of as a hard and fixed tissue, it is continually being built and rebuilt in this way. It is only by the understanding of these possibilities that we get the ideas that bone, while hard and rigid, is a plastic tissue and is continually being moulded by mechanical conditions to which it is subjected.

It will be seen also that the arrangement of the lamellæ becomes a record of the changes that have occurred in the formation of the tissue. The inner boundary of the section next to the marrow cavity will show a few layers parallel with the surface. These are known as the inner circumferential lamellæ. It is a mistake, however, to think of them as surrounding the marrow cavity in the same sense as the outer circumferential lamellæ surround the bone. If the section has been cut at a little distance from the center of the shaft, it will have been noted that the marrow cavity is penetrated by very delicate spicules, and that in fact the marrow cavity is produced by the spaces of cancellous bone, becoming larger and larger until they become one continuous space. The inner circumferential lamellæ are therefore the layers which have been formed around an enlarged nutrient or marrow space.

Cancellous Bone.—The cancellous bone can best be studied in decalcified sections. A field from the central portion of a flat bone will show its typical arrangement. It is made up of delicate

PLATE XIII



From a Ground Cross-section of the Diaphysis of the Human Metatarsus. (Szymonowicz.)

a, outer ground lamellae; *b*, inner ground lamellae; *c*, Haversian lamellae; *d*, interstitial lamellae. All canals and bone cavities are filled with coloring matter and appear black. (90 X.)

flattened spicules surrounding larger or smaller irregular spaces which connect with each other very freely. Each spicule is composed of a few lamellæ which are arranged around the space. The structure of the spicules often becomes complicated by absorptions and rebuildings which have occurred to change their direction. The tissue which fills the spaces is a delicate, embryonal connective tissue in which osteoblasts and osteoclasts appear in response to mechanical conditions. It is richly supplied with bloodvessels, nerves, and lymphatics. The lacunæ and canaliculi are in no respect different from those of the Haversian system and subperiosteal bone.

CHAPTER XVII.

BONE FORMATION AND GROWTH.

Bone is one of the latest tissues to be formed, and is always developed from an antecedent connective tissue of less specialized character. According to the character of the antecedent tissue bone formation is of two varieties—the formation from cartilage, or *endochondral* bone formation, and that from fibrous connective tissue, without the intervention of cartilage, or *endomembranous* bone formation.

Endochondral Bone Formation.—All of the bones of the endoskeleton are preformed in cartilage. The transformation of cartilage into bone is rather a substitution than a transformation, for the original tissue is destroyed in the process, and a new and more highly specialized one substituted for it.

Before ossification begins the cartilage has taken on the general form of the bone and is covered by a definite perichondrium. Ossification begins at separate centers and progresses through the cartilage, but the separate centers do not unite until the bone is about fully formed. In the long bone there are usually three centers—one near the center of the shaft, forming the hypophysis, and one near either end, forming the epiphyses. These remain separated by a layer of cartilage until the length of the bone has been fully formed.

The first indication of the transformation of cartilage into bone is an increase in the size of the lacunæ and in the amount of cartilage matrix, which also shows changes in character, having lime salts deposited in it. The cartilage cells enlarge and show signs of degeneration, the lacunæ become arranged in rows, and as they increase in size, more in the direction parallel with the axis of the cartilage, the amount of matrix separating them is reduced. By this time the perichondrium, on the surface of the cartilage opposite to the center, has developed osteoblasts which begin the formation of subperiosteal lamellæ upon the surface of the cartilage, and the perichondrium is transformed into periosteum. Opposite the center osteoclasts appear, cutting into the cartilage, followed by buds of embryonal tissue. The osteoclasts dissolve away the remains of the cartilage matrix, opening up the spaces between the lacunæ and converting the rows of lacunæ into irregular channels or primary marrow spaces. Upon the spicules of calcified cartilage matrix, osteoblasts arrange themselves and begin to lay down lamellæ of bone. These changes progress from the center in both

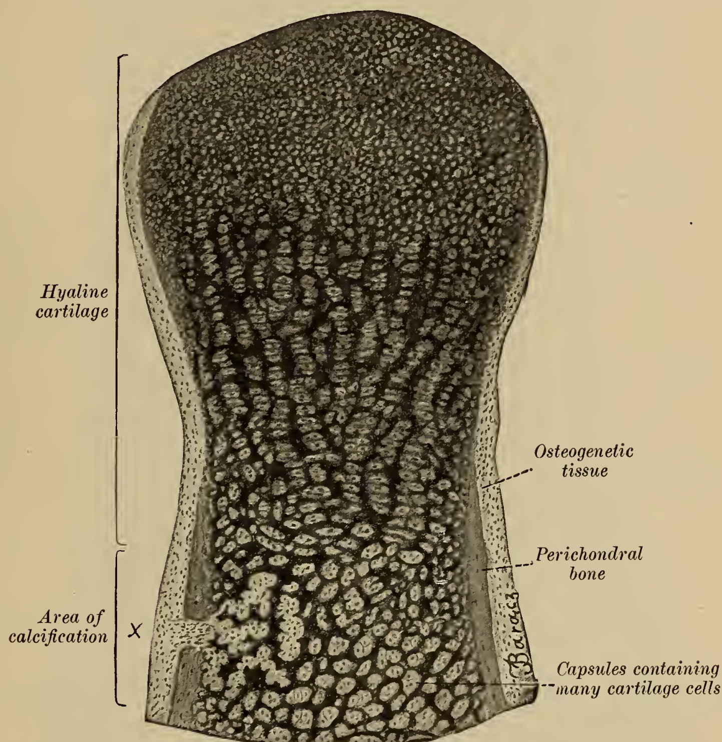


FIG. 188.—From a longitudinal section of a finger of a three-and-a-half-months human embryo. Two-thirds of the second phalanx is represented. At × a periosteal bud is to be seen. (85 ×) (Szymonowicz.)

directions, and all stages, from the typical hyaline cartilage to the formation of bone, may be seen in one section. These stages are illustrated by Figs. 188, 189, and 190.

From now on the bone grows by progressive transformation of cartilage and by the growth of bone under the periosteum, which will be considered under Bone Growth.

Endomembranous Bone Formation.—The bones which are not preformed in cartilage are formed directly from fibrous tissue. This is well illustrated in the mandible. In the region of Meckel's cartilage and between it and the developing tooth germs the mesenchyme begins to show signs of specialization. Delicate fibers appear in the intercellular substance. Along these the connective-tissue cells arrange themselves, and, taking on the form of osteoblasts, begin to lay down bone lamellæ (Fig. 191). These stretch out

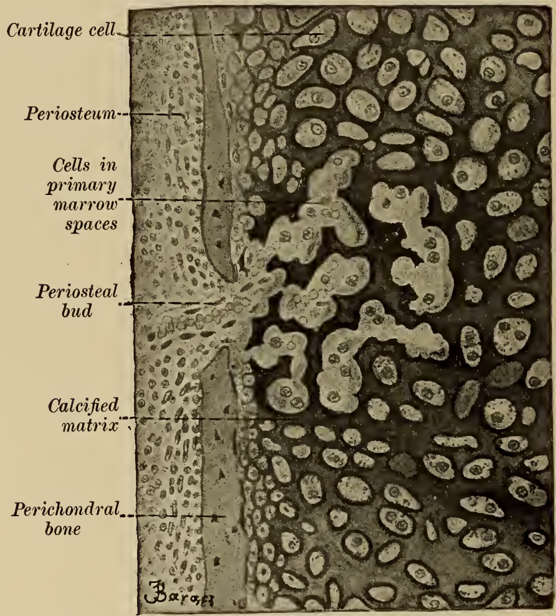


FIG. 189.—The place marked × in the preceding figure with stronger magnification. (185 ×) (Szymonowicz.)

through the mesenchyme, forming a network of delicate spicules, until they surround Meckel's cartilage, and grow up to the buccal and the lingual of the tooth germs. As soon as this network of bone lamellæ, containing embryonal connective tissue in its primary marrow spaces, begins to take on definite form, there is a specialization of the mesenchyme surrounding it, developing into fibrous tissue which becomes a periosteum. From this time onward the formation of bone progresses, as will be described under the growth of bone.

Bone Growth.—If sections are cut transversely through the shaft of a long bone from a fetus, the surface will be found to be covered by a well-formed periosteum, which is actively laying down layers of subperiosteal bone. The central portion of the bone is made up of a network of spicules surrounding primary marrow spaces,

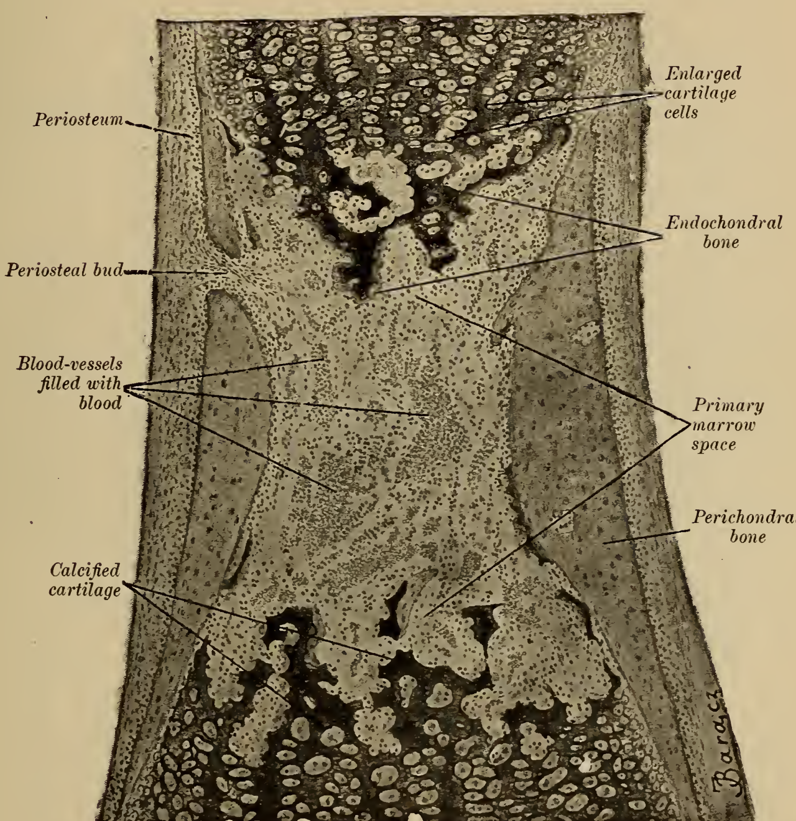


Fig. 190.—From longitudinal section of a finger of a four months embryo. Only the diaphysis of the second phalanx is represented. (85 ×) (Szymonowicz.)

there being no true marrow cavity. The formation of the subperiosteal layers does not progress at a uniform rate at all points on the circumference, but they are piled up at certain points forming longitudinal ridges with grooves between them. These grooves become arched across, enclosing part of the connective tissue of the inner layer of the periosteum, and contain bloodvessels and nerves. Soon after these spaces are enclosed absorptions begin in their walls, destroying a large part of the subperiosteal lamellæ and forming primary marrow spaces. As soon as these spaces have reached a certain size the absorptions stop, and osteoblasts appear upon the wall of the space and begin to lay down lamellæ

Fig. 191.—Section through the lower jaw of an embryo sheep (decalcified with picric acid). At *a* and immediately below are seen the fibers of a primitive marrow cavity lying close together and engaged in the formation of the ground substance of the bone, while the cells of the marrow cavity, with their processes, arrange themselves on either side of the newly formed lamellæ and functionate as osteoblasts. (Bohm, Davidoff, Huber.) (300 ×)

upon its circumference, until an Haversian system has been produced with an Haversian canal at its center. In this way the bone increases in diameter, and this process continues until a considerable thickness of Haversian system bone is formed. In all bone growth there is the alternation of formation, destruction, and rebuilding, and it must be remembered that this continues as long as the bone functions as an organ of support. As the shaft becomes larger the primary marrow spaces at the center are enlarged by the absorption, and a few lamellæ are laid down again upon their walls, until finally in the central portion of the shaft the true marrow cavity is formed. As the thickness of Haversian system bone becomes greater, absorptions occur in the Haversian canals, cutting out large, irregular channels, around which a few lamellæ are laid down, and so the Haversian system bone becomes converted into cancellous bone and is opened into the marrow cavity as it grows larger.

Growth of Membrane Bones.—The growth of the membrane bone progresses in a very similar way. As soon as the periosteum is formed subperiosteal bone is laid down and converted into Haversian system bone, forming the compact plate of the surface, leaving the cancellous portion first formed at the center. When a certain thickness of compact bone has been formed, absorptions occur in the Haversian canals, converting the deeper portions into cancellous bone. This process may be reversed. Absorptions may occur under the periosteum, cutting deeply into the Haversian system bone, and then a few subperiosteal layers laid down upon it. When this occurs lamellæ are laid down around the marrow spaces, converting the cancellous bone into Haversian system bone to maintain the required strength. In this way the bones are moulded into shape, adapting them to the mechanical conditions to which they are subjected. There is an oscillation between formation and destruction, by which the balance adapted to the mechanical conditions is maintained. It has often been noted that bones are never allowed to become more bulky than is necessary to perform their function.

CHAPTER XVIII.

PERIOSTEUM.[1]

Definition.—The periosteum is the formative and protective membrane which covers the outer surface of the bone. All periosteum has certain structural characteristics in common, but because of structural differences two classes are recognized—attached and unattached—each of which may be simple or complex. Periosteum may thus be classified as follows:

1. Unattached simple.
2. Unattached complex.
3. Attached simple.
4. Attached complex.

Function of Periosteum.—The importance to the dentist of a knowledge of the structure and function of the periosteum can scarcely be exaggerated. It has been the knowledge of this tissue and its function that has led to all the advancement in bone surgery of modern time. Repair and regeneration of bone is largely accomplished through its agency.

The periosteum forms the immediate covering of all the bones and is continuous over their entire surface except the portion covered by cartilage. Each bone therefore has a periosteum of its own which does not continue around the articulation to the bones with which it joins. Bones that are united by suture are, however, covered by a common periosteum. If the flesh and overlying tissues are carefully removed from a long bone, the periosteum will be seen as a smooth white, lustrous membrane, having much the same appearance of a tendon on most of its surface. But at some places which correspond to the positions where muscles or fascia

[1] In the presentation of this chapter it is impossible adequately to express my indebtedness to Dr. G. V. Black. Almost all of the illustrations are taken from The Periosteum and Peridental Membrane, published by him in 1887. I have always felt that this book had never received the attention it deserves. Only one thousand copies of it were printed, and they were not sold until the orthodontists exhausted the edition. The book is now entirely out of print and is very difficult to obtain. I have studied this book for years and have repeated almost all of the work described in it, but I have felt that it was impossible for text-book purposes to improve upon the illustrations.

were attached it appears ragged and dull, for the tissues had to be cut to separate them from the outer layer of the periosteum, to which they were firmly adherent. In all other places the tissues separate easily in dissection; in fact, are not attached at all, except by the lightest of areolar tissue, which is very easily broken, and the tissues may be separated from the surface of the membrane with the finger or the handle of a scalpel. Now, if the periosteum is slit along a smooth surface with the scalpel and the handle inserted between the bone and the membrane, it will be found to separate readily from the bone over most of its surface. If the process is watched closely, little strings will be seen apparently running from the periosteum to the bone, and being broken as they are separated. These are mostly small bloodvessels which are running into canals in the bone. In this process the periosteum seems like a closely adapted sac or elastic glove, clothing the surface of the bone, as if surrounding it in a fibrous bag. If the separation of the periosteum from the bone is continued, it will be found that it does not separate as easily in all places. As the articular ends are approached it becomes suddenly fastened to the underlying bone, and the blade of the knife must be used. The periosteum now appears as a very thin, tough, and inelastic membrane, that is torn with difficulty, but it is so thin that it is difficult now to separate it from the bone without cutting it through. When this point of attachment is reached it seems that the periosteum is sinking into the substance of the bone, and from the examination of its structure it is found that this is practically what has happened.

Comparing the periosteum to a sac surrounding the bone, it is found sewed firmly down at the margin of the cartilage around the articular ends. Besides the attachment around the cartilage, the periosteum will be found adherent in the following positions: Where muscles or fascia are attached to the outer layer of the periosteum; where it approaches the insertion of tendons or ligaments; and where the skin or mucous membrane seem attached to the underlying bone, as around the auditory meatus, the gums, mucous membrane of the nose, etc. In all such positions the periosteum is firmly attached to the bone—in fact, becomes a part of it—and through this medium the connections between muscles, fascia, etc., and the framework of the skeleton is accomplished.

This feature of the anatomy of the periosteum has never been studied in the detail it deserves, especially by the dentist. It is of the greatest importance in the management of the diseases of bone, especially those involving the formation of pus, for these lines of attachment determine the direction in which the pus will proceed along the surface of the bone. When pus generated within the bone reaches the surface, it will lift an unattached periosteum and run along the surface until it reaches a line of attachment. Here it can penetrate the periosteum more easily than it can separate it from the bone. When a line of attachment is reached, therefore, the direction of the burrowing is determined by the attached areas. The pus penetrates the periosteum more easily than it separates its attachments from the bone, but it lifts the unattached periosteum so easily that it will often run along a line of attachment for a long distance.

These factors often become of great importance in determining the position in which alveolar abscesses will point. For instance, if an abscess from a bicuspid root, or the mesial root of a molar, reaches the surface of the bone above the attachment of the buccinator, it cannot penetrate its attachment and pass downward to open on the gum, but may run out over the surface of the muscle and open on the cheek, producing the crow's foot scar so often seen. An abscess from an upper cuspid may reach the surface of the bone in the canine fossa between the attachments of the nasalis and caninus, and lift the periosteum extending upward, and open at the inner canthus of the eye between the orbicularis and the angular head of the quadratus labii superioris. If these abscesses had been reached with a lance, through the mucous membrane, at the proper time, a disfiguring scar would have been avoided. Accurate knowledge of the attached layers of the periosteum would have made it certain that they could never point in the mouth cavity without assistance.

Layers of the Periosteum.—Periosteum is always composed of two distinct layers:

1. An outer or fibrous layer, which is essentially protective and to which muscles and fasciæ are attached. This may be either simple or complex.

2. An inner or osteogenetic layer which is essentially the vital functioning layer, and is, as its name indicates, concerned with the formation of bone. This may be either simple or complex.

The Structural Elements.—The periosteum is composed of the following structural elements:

1. White fibers in coarse bundles (in the outer layer).
2. White fibers in very fine bundles (in the inner layer).

3. Elastic fibers.
4. The penetrating fibers, or white fibers of the periosteum, that in the growth of bone are included in its substance.
5. Embryonal connective-tissue cells.
6. Osteoblasts or bone-forming cells.
7. Osteoclasts or bone-absorbing cells.

Unattached Periosteum.—In the unattached periosteum the inner layer is always simple, and the outer layer may be either simple

Fig. 192.—Non-attached periosteum from the shaft of the femur of the kitten: *B*, bone; *O*, layer of osteoblasts. In the central portion of the figure they have been pulled slightly away from the bone, displaying the processes to advantage. It will be observed that the fibers of the periosteum do not enter the bone. *a*, inner layer of fine white fibrous tissue (osteogenetic layer) showing the nuclei of the fibroblasts and a number of developing connective-tissue cells, which probably become osteoblasts; *c*, outer layer, or coarse fibrous layer, in which fusiform fibroblasts are also rendered apparent by double staining with hematoxylin and carmine; *d*, some remains of the reticular tissue connecting the superimposed tissue with the periosteum. ($\frac{1}{12}$ immersion.) (Black.)

or complex, depending apparently upon the requirements of protection. In general, the more exposed the position the thicker is the layer, and the larger and stronger the bundles of fibers of which it is composed.

Simple Unattached Periosteum.—Where the periosteum is covered by a thick layer of muscles which are not attached to it, as in the thigh, the thinnest and simplest form of periosteum is found. An illustration, drawn by Dr. Black, of the periosteum from the femur of a kitten will illustrate its structure (Fig. 192). The outer layer is composed chiefly of bundles of white fibers, most of which run in a direction parallel with the long axis of the bone. The bundles are comparatively small and much flattened, so as to be quite ribbon-like. The inner layer contains a much greater number of cells lying among extremely delicate fibers. In its outer portion many of the cells are embryonal in character. In contact with the surface of the bone is a continuous layer of osteoblasts which are building subperiosteal bone in the young animal, processes of

FIG. 193.—Periosteum from the shaft of the tibia of the pig, lengthwise section, showing the complex arrangement of fibers in the coarse or outer fibrous layer that sometimes occurs under muscles that perform sliding movements upon it: *B*, bone; *O*, layer of osteoblasts. The tissue has been pulled slightly away from the bone in mounting the section, and part of the osteoblasts have clung to the bone, some have clung to the tissues, while others are suspended midway, their processes clinging to each. *a*, layer of fine fibers; inner or osteogenetic layer of the periosteum; *b*, first lamina of the coarse or outer fibrous layer, the fibers of which are, in this case, circumferential, exposing the cut ends. It will be observed that there are ten lamina in the make up of the outer layer, the lengthwise and circumferential fibers alternating. The ones marked *f* and *i* are very delicate ribbon-like forms, which have shifted from their normal position in the mounting of the section, so as to present their sides to view instead of their ends, thus displaying their structure to advantage. The illustration shows how readily separable these lamina are. *l*, reticular tissue. ($\frac{1}{12}$ immersion.) (Black.)

their cytoplasm extending into the canaliculi of the matrix which they have formed. At one point in the illustration the osteoblasts are pulled off from the surface of the bone and show these processes stretched out of the canaliculi.

Complex Unattached Periosteum.—In some places, especially where muscles or tendons perform sliding movements over an unattached periosteum, the outer layer, instead of being simple, may be very complex. This is illustrated in Dr. Black's drawing

(Fig. 193), from the periosteum of the tibia of a young pig. In this instance the outer layer is composed of very much flattened bundles of white fibers, arranged alternately longitudinally and circularly. Ten layers may be counted in the section. The inner layer is of the same character as in a simple specimen.

Attached Periosteum.—The attached periosteum differs from the unattached by having the fibers of the inner layer arranged in bundles, around which the bone matrix is deposited by the osteoblasts, embedding them in the substance of the matrix and calcify-

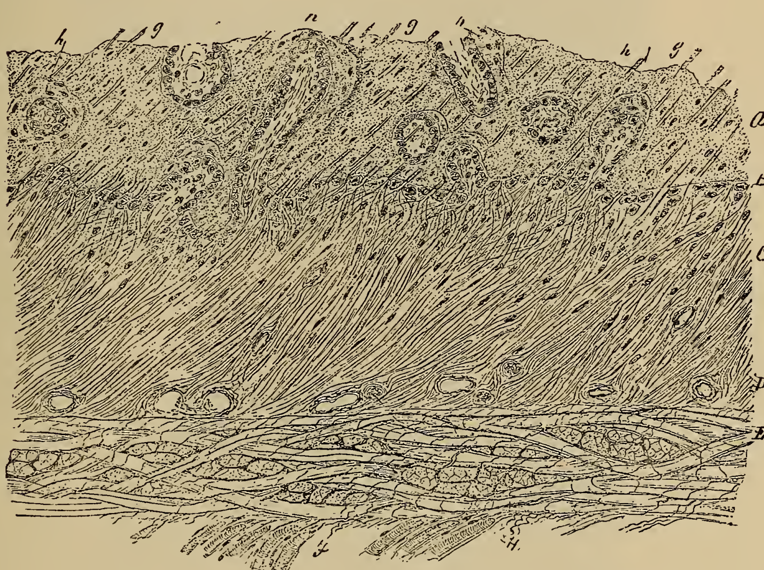


Fig. 194.—Simple attached periosteum: *a*, bone; *b*, osteoblasts; *c*, fibers of the inner layer; *D*, bloodvessels of the inner layer; *E*, outer layer; *F*, muscle fibers attached to outer layer. (Black.)

ing them with it. These fibers constitute the penetrating fibers. They were first described by Sharpey, and have been called Sharpey's fibers. He, however, apparently did not understand their importance or manner of formation. The fibers of the inner layer are built into the substance of the bone in this way wherever tissues are attached to the outer layer of the periosteum.

Simple Attached Periosteum.—Where the pull of tissues attached to the outer layer of the periosteum is in one direction, the fibers of the inner layer are inclined in the same direction (Figs. 194 and

195). As the surface of the bone is approached the fibers are gathered into strong bundles to be inserted in the bone, the osteo-

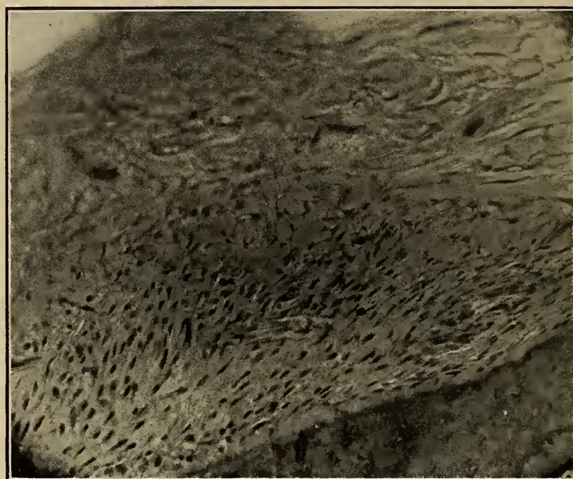


Fig. 195.—A photomicrograph of an attached periosteum similar to Fig. 194. From the alveolar process of a sheep. (About 80 ×)

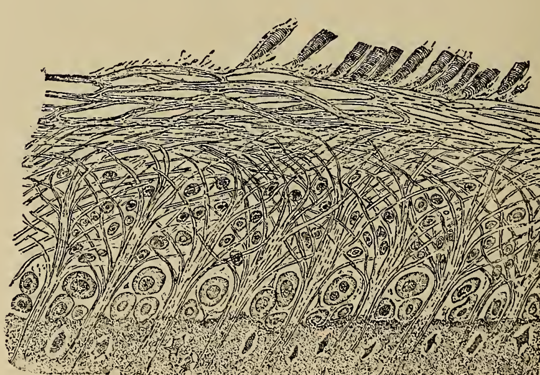


Fig. 196.—Attached periosteum from beneath the attachment of the muscles of the lower lip of the sheep: *A*, bone; *B*, osteoblasts, with the fibers emerging from the bone between them; *C*, inner layer with fibers decussating and joining the inner side of the coarse fibrous layer in opposite directions (this is rather an unusual form of this layer of the periosteum); *D*, coarse, fibrous layer; *E*, attachment of muscular fibers. (Black.)

blasts covering the surface of the bone everywhere between the fibers. The outer and inner layers are united by the interlacing of their fibers. At the junction of the outer and the inner layers many bloodvessels are seen.

Complex Attached Periosteum.—Where the pull upon the outer layer is in many directions, the fibers of the inner layer, after emerging from the bone, break up into smaller bundles and anastomose in all directions, arching around to interlace with the fibers of the outer layer, and in this way they sustain force in all directions (Fig. 196). This is illustrated in Dr. Black's drawing of a section of attached periosteum from beneath the attachment of the muscles of the lower lip of a sheep.

CHAPTER XIX.

THE ATTACHMENT OF THE TEETH.

THAT the teeth are not a part of the osseous system, but are appendages of the skin, supported in man by a special development of bone forming the alveolar ridges of the maxillary bones, is as well established as any fact concerning human dentition. The work of Oscar Hertwig, published in 1874, established very clearly the homology existing between the teeth and the dermal or placoid scales of the ganoid, silurioid, and dipnoan fishes, both as to similarity of structure and development.

Much has been written descriptive of the teeth of various animals, their modifications of form, and attachment to adapt them to modifications of function, and various classifications of the means of attachment have been made. Of these, perhaps the best and most logical is given by Charles Tomes in his *Dental Anatomy*, describing four forms of attachment: (1) By fibrous membrane; (2) by hinge-joint; (3) by ankylosis; (4) by insertion in a socket or gomphosis.

These various forms of attachment will be taken up, and, if possible, the comparison between them and the evolution of the more complicated forms from the simpler will be shown. The study must begin with an examination of the structure and attachment of the placoid scales and the simplest form of tooth, as illustrated in the shark.

Structure of Dermal Scales.—The dermal scales are composed of a conical cap of calcified tissue developed from within outward, by an epithelial organ, and corresponding in structure to the enamel. This cap is supported upon a conical papilla of calcified tissue formed from without inward, and corresponding to dentin. In the outer layer the arrangement of the fine tubules through the calcified matrix correspond very closely to human dentin, but in the inner portions it is to be understood only by considering the formation of the dentin as progressing irregularly over the surface of the pulp and so dividing the pulp tissue into portions enclosed in large canals, from which the fine tubules radiate. The base of this partially calcified papilla has a calcified connective tissue built on to it by the derma or connective-tissue layer of the skin, which corresponds to cementum forming the basal plate, spreading out more or less in the connective-tissue layer of the skin, and into which the fibers of this layer are built, so attaching the denticle or dermal scale to the deep layer of the coreum. This tissue very exactly resembles cementum. It is formed on the dentin as the cementum of a human tooth is, and shows the connective-tissue fibers embedded in it. In the ganoids the basal plates of adjoining scales unite, forming the armor plates of such fish as the sturgeon and gar-pike, and the dentical remains projecting from the surface of the plates.

Fig. 197.—Showing additions of bone of attachment to the bone of the jaw. (Tomes.)

Attachment by Fibrous Membrane.—In the simplest teeth, as of the shark (Lamna cornubica, Fig. 3), which are typical dermal scales, there is an exactly similar method of attachment, which may be taken as the simplest and most rudimentary, or attachment in a fibrous membrane. That is, there is no development or modification of the arch of the jaw, and the teeth have no direct attachment to the bone; in fact (Fig. 197), the jaws themselves are chiefly cartilage.

Attachment by Hinge Joint.—The formation of the hinge attachment as illustrated in many of the fishes (Fig. 198), may be understood as a modification of the attachment in a fibrous membrane in a more highly specialized creature. These hinged teeth are found in many fishes and in the poison fangs of snakes. The jaws are calcified, and the basal plate or cementum may be considered as confined to, or specially developed on, one side of the dentin papilla, which is also more highly developed, especially in snakes. This cementum is built and calcified around the fibers of the fibrous tissue which pass directly to the bone of the jaw

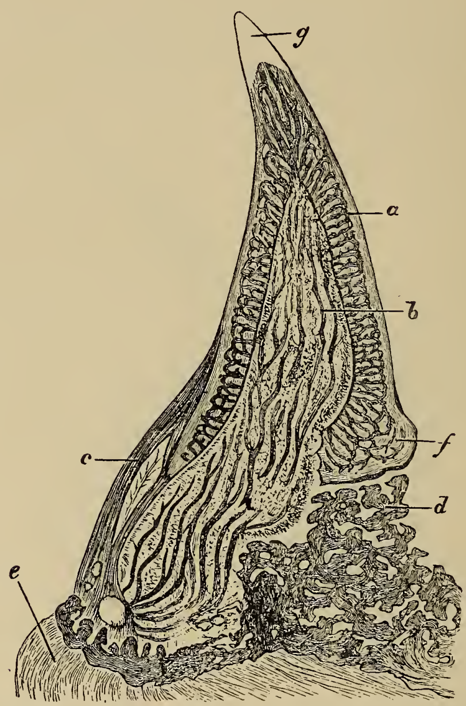


Fig. 198.—Attachment by hinge joint. Tooth of a hake: *a*, vasodentin; *b*, pulp; *c*, elastic hinge; *d*, buttress to receive *f*, formed out of bone of attachment; *e*, bone of jaw; *f*, thickened base of tooth; *g*, enamel tip. (Tomes.)

at that point. This bone is to be regarded as an addition to the jaw specially developed for each tooth. Thus, there is not only a modification in the arrangement of the cementum, but a development of bone for attachment of the tooth. The bloodvessels pass through the fibers of the hinge to the pulp, and are not affected by the motion of the tooth on the hinge; in fact, the pulp seems to be attached to the hinge. There are many complications of this method of attachment, but this may be taken as the type and the manner of its modification from the rudimentary conditions. The distinction, in this form of attachment, from the dermal scale consists in a modification of the arrangement of the cementum of the basal plate and a development of bone from the jaw to attach fibers which pass directly from cementum to bone. It should also be said that there are developments in the hinge teeth related to the third form of attachment, namely, ankylosis, which cannot be understood until this form is studied.

Attachment by Ankylosis.—The third form of attachment, ankylosis (Fig. 199), or direct calcified union with the bone of the jaw, cannot be understood without a careful study of the nature and formation of the dentin in these rudimentary teeth. It is evident, from a study of the dentin of the dermal scales, that compared with human dentin, the tissue is rudimentary and not differentiated from other similar connective tissues. The tubules are comparatively very irregular, and resemble strikingly the tubules found in the secondary dentin formed by a degenerating pulp. The odontoblasts, or dentin-forming cells, are not like the highly specialized cells which form the primary human dentin, but resemble very closely simple spindle-shaped connective-tissue cells. The nucleus is larger and oval in form, and the protoplasm stretches off from it in one direction into a fibril instead of in two directions into a spindle. The cells are much smaller than human odontoblasts and nearer the size of ordinary spindle cells of the human pulp. In fact, they look more like specially developed spindle cells than odontoblasts. The formation of dentin begins on the surface, at the apex of a cone-shaped papilla of connective tissue, and proceeds inward. If the formation continues uniformly over the surface of the papilla, a solid layer of fine-tubuled dentin results; but it often proceeds irregularly, apparently having special reference to the neighborhood of bloodvessels, so that irregular projections of dentin are found on its inner surface, dividing the pulp more or less into portions enclosed in larger channels or tubes. These may be very regular in arrangement and form around bloodvessels loops embedding the bloodvessel in the calcified tissue, producing what has been called vaso or vascular dentin; but the formation is still from the surface of the pulp until it is obliterated, except for what remains in the larger canals. As distinguished from this formation of dentin we find in the body of the dental papilla of many fishes the formation of spicules of calcified tissue, which resemble neither dentin nor typical bone, shooting down through the substance of the pulp. They are more to be compared with the first formation of bone in membranes, or in the embryonal connective tissue of the body of the human jaw, which is afterward

FIG. 199.—Tooth of scarus, showing attachment by ankylosis: *1*, vertical section of five pharyngeal teeth of Scarus muricatus; *2*, section of a single tooth magnified: *a*, osteodentin; *b*, dentin; *c*, enamel; *d*, cementum; *3*, termination of a single dentinal tubule. (Owen.)

removed by absorption and replaced by true Haversian system bone. These calcifications contain lacunæ, and have tubules or canaliculi running through them, and so, as Tomes says, are intermediate between dentin and bone. They divide the pulp into irregular spaces, and interdigitate, or perhaps actually join, the formation of dentin which has been progressing from the surface of the pulp. These spicules run down into the bone of the jaw, forming an actual calcified attachment for the tooth with the jaw; but in this view of it, it is to be regarded as a calcification or rather a formation of bone in the pulp papilla interlocking with the dentin. In some of the fishes, as in Scarus, there is at the same time the remains of the cementum of the basal plate formed on the outside of the dentin around the base of the cone. Ankylosis is confined to the teeth of many fishes, and may be stated as a modification from the dermal scale, resulting in the reduction or loss of

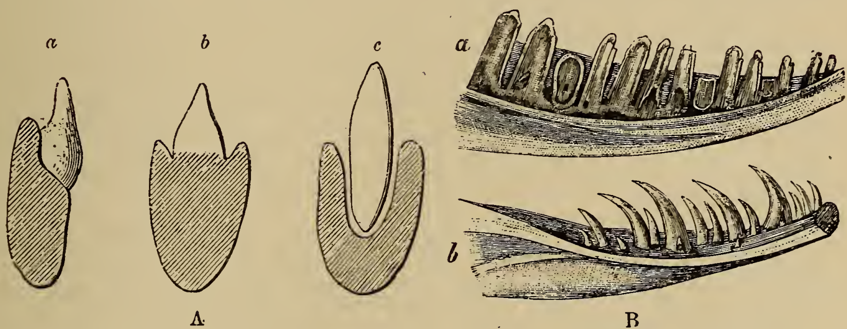


Fig. 200.—*A*, diagrams of tranverse sections through the jaws of reptiles showing pleurodont (*a*), acrodont (*b*), and thecodont (*c*) dentitions. *B*. *a*, lower jaw of Zoötoca vivipara; *b*, of anguis fragilis. (After Leydig.) Weidersheim, Comparative Anatomy of Vertebrates.)

the basal plate and an ossification of the pulp continuing through the connective tissue at the base of the pulp to the body of the jaw.

Attachment by Implantation in Socket.—The development of the fourth form of attachment, by implantation in a socket, seems to be an evolution starting from the same point but proceeding in a different direction (Fig. 200). It is associated with the very great increase in the size of the teeth and consequent necessity for a stronger attachment. The evolution of this is illustrated in the teeth of reptiles. Weidersheim classifies the teeth of reptiles as (1) resting upon a ledge on the lingual side of the jaw—pleurodont dentition; (2) resting on a slight ridge around them—acrodont dentition; (3) lodged in permanent alveoli, as in the crocodile—thecodont dentition. These three classes illustrate three stages in the development of the socket method of attachment.

In the simplest form there is a cone-shaped tooth, attached to the bone around its base, by the fibers being built into the cementum and bone. There is little modification of the rudimentary form, and little development of bone for its attachment. In a higher form the tooth has become long or peg-shaped, and the bone has grown up around a portion of it to support it; but it is attached to the bone by connective-tissue fibers, being built into the cementum on the surface of the tooth and into the bone of attachment on the jaw. The development of the form of the tooth to the peg from the cone may be understood as a continuing of the development of odontoblasts, and the formation of dentin (which always begins at the apex of the cone) farther and farther down the sides of the dental papillæ. Then the formation of the cementum, which begins around the base of the cone and continues down on the outside of the calcified dentin, covering its outer surface, and building the connective-tissue fibers into the tooth. The development of bone accompanies, or rather follows that of the tooth, building the other ends of these fibers into the bone which is developed to support the tooth.

Summary.—To review the subject matter of this chapter, all teeth have been evolved from the simple placoid scale. In the simplest forms, as in the teeth of the shark, there is no relation to the bone whatever, but the fibers of the subcutaneous tissue are built into the basal plate of cementum. As the tooth becomes larger and demands more support, there is added to the bone of the jaw that which Tomes has called bone of attachment. The osteoblasts build up additions to the jaw which surround and embed the fibers, so that the fibers which were originally in the subcutaneous tissue are fastened to the bone at one end and to the cementum at the other. The evolutions of attachment by hinge joint and by gomphosis are therefore direct evolutions from the simple attachment in membrane. The form of ankylosis is also evolved from the simplest type, but in this case the bone of attachment is associated with the pulp, and the formation of bone and dentin become interlocked and united.

CHAPTER XX.

THE PERIDENTAL MEMBRANE.

In one sense the peridental membrane may be considered as the most important tissue to the dentist, for upon it the usefulness of the teeth and their comfort to the individual is dependent. It makes no difference how perfect a crown may be, or how perfectly any damage which may have occurred to it may have been restored, unless the peridental membrane is in a healthy and fairly normal condition, the tooth will be useless, and the individual would be much more comfortable without it.

Definition.—The peridental membrane may be defined as that tissue which fills the space between the surface of the root and the bony wall of its alveolus, surrounds the root occlusally from the border of the alveolus, and supports the gingivæ. It is necessary to emphasize the three parts of the definition. The peridental membrane does not stop at the border of the bone, but continues to surround the root as far as the tissues are attached to it. In general, the dental profession has thought of the peridental membrane as only that tissue which occupies the space between the root and the wall of its alveolus. As will be seen from a study of sections later (Figs. 203 and 204), the structure of the tissue surrounding the root between the gingival line and the border of the process is essentially the same as that in the alveolus, and quite different from the much coarser fibrous mat forming the submucous layer of the gum tissue. The peridental membrane also extends into the free margin of the gum and is the means of its support, holding the gingivæ close to the surface of the tooth and supporting them in the interproximal spaces. The importance of this portion of the peridental membrane and the functions which it performs have been strongly emphasized in the last few years, in their relation to the extensions of caries and the beginnings of pyorrhea. Most of the diseases of the peridental membrane which result in the final loss of the teeth have their beginnings in this portion.

Nomenclature.—The peridental membrane belongs to the class of fibrous membranes which form the covering of organs, the capsules of glands, and especially those membranes which cover the organs of support. Its closest relative is the periosteum in the attached portions, with which it has many points of structure in common, but it differs from the periosteum in any position in important respects. It has often been called the alveodental periosteum, but this name implies that the periosteum is folded down into the alveolus and back upon the surface of the root, which is an entirely erroneous conception of the membrane. This idea would imply that it was a double membrane having one layer covering the bone and another covering the root, the two uniting in the middle portions. But instead, the periosteum must be

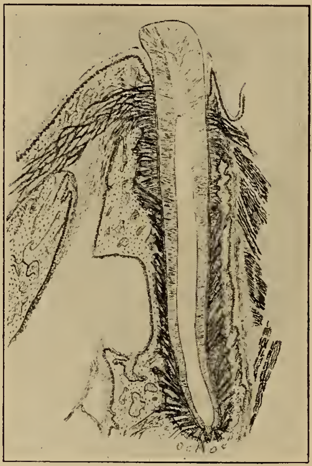


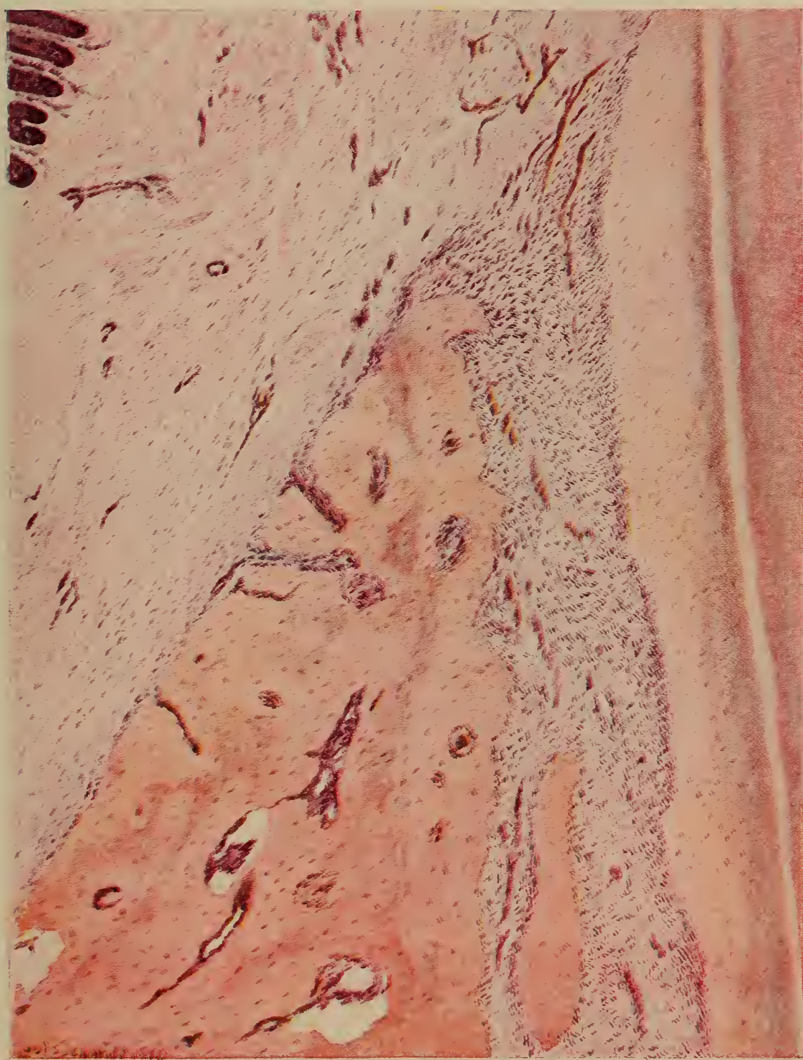
Fig. 201.—Drawing to show the arrangement of the fibers in a labiolingual section through an incisor of a kitten. (Black.)

considered as stopping at the border of the alveolus,[1] and being united with the peridental membrane around its circumference. Many writers use the word pericementum in place of peridental membrane. The author prefers, and in this book will use, the term peridental membrane, though the two are synonymous.

Divisions.—Purely for convenience in description, the peridental membrane is divided into three portions: The *gingival portion,* that portion of the membrane which surrounds the root occlusally

[1] The student must be reminded that the word alveolus means a hole, and the alveolar process, the portion of the bone which contains the holes. In dental writing the word alveolus has often been incorrectly used in place of process or alveolar process.

PLATE XIV



Longitudinal Section of Peridental Membrane.

Stained with hematoxylin and eosin. Showing border of alveolar process.

from the border of the alveolar process and supports the gingivæ; the *alveolar portion,* the portion of the membrane from the border

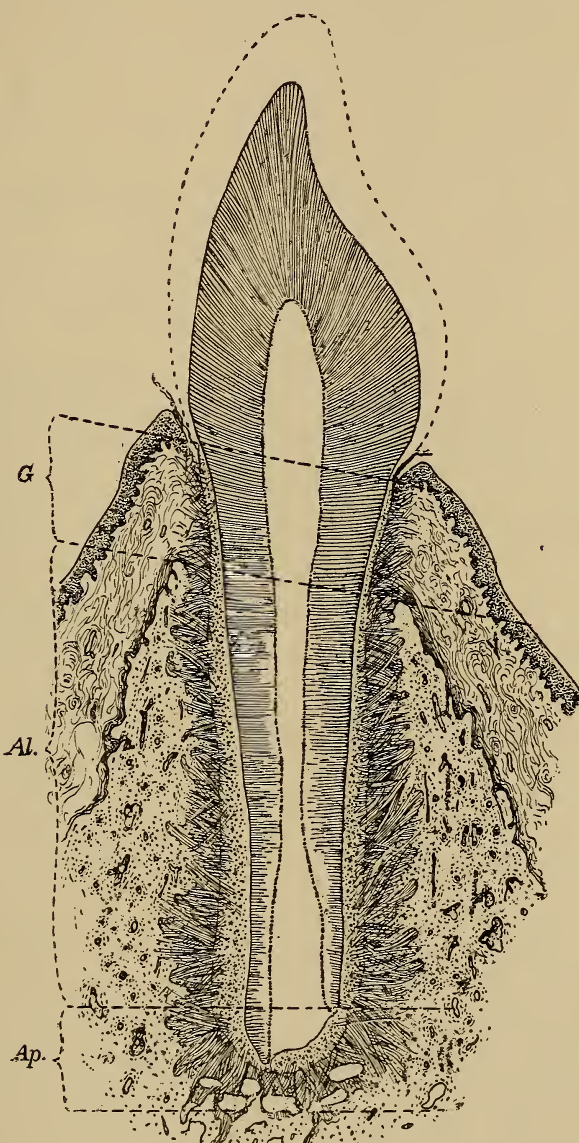


FIG. 202.—Diagram of the fibers of the peridental membrane: *G*, gingival portion; *Al.*, alveolar portion; *Ap.*, apical portion. (From a photograph of a section from incisor of sheep.)

of the process to the region of the apex of the root; and the *apical portion,* which surrounds the apex of the root and fills the apical space. These are illustrated in the diagram (Figs. 201 and 202).

The Structural Elements.—These are: (1) White connective-tissue fibers; (2) fibroblasts; (3) cementoblasts; (4) osteoblasts; (5) osteoclasts; (6) epithelial structures which have sometimes been called the glands of the peridental membrane; (7) bloodvessels; (8) nerves; (9) lymphatic vessels.

Functions.—The peridental membrane performs three functions: (1) A physical function—it maintains the tooth in relation to the adjacent hard and soft tissues. (2) A vital function—the formation of bone on the alveolar wall and of cementum on the surface of the root. (3) A sensory function—the sensation of touch for the tooth being exclusively in this membrane.

It is necessary to emphasize the two parts of the physical function; the peridental membrane not only supports the teeth in their relation to the bones which carry them, and sustains them against the forces of occlusion and mastication, but it also sustains the soft tissues in their proper relation to the teeth. The second part of the physical function is fully as important as the first, and the study of the structure of the tissue related to it and the adaptation of the form of the gingivæ to the anatomic form of the teeth and alveolar process, are important considerations which should never be lost sight of in the making of artificial crowns.

Classes of Fibrous Tissue.—The fibrous tissue of the peridental membrane is entirely of the white variety, but may be divided into two classes. The *principal* fibers and the *indifferent* or *interstitial* tissue. The former perform the physical function of the membrane, the latter simply fill in spaces between the bundles of fibers and surround and accompany the bloodvessels and the nerves.

The Principal Fibers of the Peridental Membrane.—These may be defined as the fibers which, springing from the cementum, are attached at their other extremities to the connective tissue supporting the epithelium, the fibrous mat of the gum tissue, the cementum of the approximating tooth, the outer layer of the periosteum at the border of the alveolar process, or the bone of the alveolar wall.

Arrangement.—The principal fibers literally spring from the cementum, the cementoblasts building up the matrix around them and then calcifying both the matrix and the fibers, in this way attaching them to the surface of the root. In most places the fibers as they spring from the cementum appear as good-sized bundles. A short distance from the surface of the root they may break up into smaller bundles which anastomose and interlace, passing around bloodvessels and other fibers in their course and being again united into large bundles for attachment at their other extremity.

To arrive at an understanding of the arrangement of the fibers of the peridental membrane, sections must be cut longitudinally, both from buccal to lingual and from mesial to distal, and transversely through all portions of the membrane. It therefore requires the study of many sections to work out a complete conception. After studying them out completely in this way one is impressed with the beautiful adaptation of their arrangement to sustain the tooth against all the forces to which it is subjected, and to support the free margin of the gum, so that it will lie closely against the gingival portion of the enamel. It is necessary, however, to remind the student that connective tissues are formed in response to mechanical conditions and stimuli, and therefore this arrangement must be considered, not as having been designed to sustain the forces, but as being the result of the forces to be sustained, and therefore beautifully adapted to them.

The principal fibers of the peridental membrane are naturally divided into a number of groups which differ in their arrangement and function. In his latest book, *Special Dental Pathology,* Dr. Black has given descriptive names to these groups. Passing from the gingival line toward the apex of the root these groups are: (1) The *free gingival group,* the fibers of which pass from the cementum occlusally into the gingiva to support it; (2) the *trans-septal group,* passing from tooth to tooth, and supporting the interproximal gingivæ; (3) the *alveolar crest group* passing from the cementum to the outer layer of the periosteum on the labial and lingual and to the crest of the alveolar process on the mesial and distal; (4) the *horizontal group* in the occlusal third of the alveolar portion and passing at right angles to the axis of the tooth from the cementum to the bone; (5) the *oblique group* in the apical two-thirds of the alveolar portion and inclined occlusally as they pass from cementum to bone; (6) the *apical group,* the group of fibers radiating from the apex of the root to the bone around the apical space.

Beginning at the gingival line, the fibers springing from the cementum pass out at a short distance at right angles to its surface and then bend sharply to the occlusal, passing up into the gingivæ and uniting with the fibrous mat which supports the epithelium. These are much more strongly marked on the lingual than on the labial gingivæ, because in mastication the lingual gingivæ receives more pressure of food, which would tend to crush it down (the free gingival group). A little deeper the fibers springing from the cementum on the labial and lingual pass out at right angles to the cementum and are lost in the coarser fibrous mat of the gum tissue. The distance which they extend before being lost in the coarser fibers is always greater on the lingual than on the labial. On the proximal sides the fibers springing from the cementum at the same level, branch and interlace, passing across the interproximal space, to be attached to the cementum of the approximating tooth. These fibers are of the greatest importance, as they produce the basket work which forms the supporting framework for the interproximal gingivæ (the trans-septal group). A little farther apically the fibers as they come from the cementum are inclined apically. A short distance from the cementum they unite into very large and strong bundles which join with the fibers of the outer layer of the periosteum, extending over the labial and lingual border of the alveolar process (the alveolar crest group). On the proximal sides the fibers at this level are attached to the cementum of the adjoining tooth, or are inclined apically, to be inserted in the bone of the septum (the alveolar crest group). These large bundles form a distinct layer, which has been called the *dental ligament,* because they bind the teeth together across the septum and attach them to the outer layer of the periosteum on the labial and lingual borders of the alveolar process. They are the only fibers which hold the teeth down in its socket. At the border of the alveolar process, and in the occlusal third of the alveolar portion, the fibers pass directly from the cementum to the bone at right angles to the axis of the tooth (the horizontal group). In this position the fibers are larger and stronger, and show less tendency to break up into smaller bundles in their course than in any other portion of the membrane. In the middle and apical thirds of the alveolar portion the fibers are inclined occlusally as they pass from the cementum to the bone. They spring from the cementum in compact bundles, and show a strong tendency to break up into fan-shaped fasciculi, spreading out as they approach the bone, to be attached over a larger area of the alveolar wall. These fibers literally swing the tooth in its socket and support it

PLATE XV

Longitudinal Section of Peridental Membrane.

Stained with hematoxylin and eosin. Showing part of the lingual gingivus and border of the alveolar process.

against the forces of mastication (the oblique group). In the apical region fibers springing from the cementum pass out in all directions, spreading out in the same way, to be inserted into the bone forming the wall of the apicals pace (the apical group).

If force is exerted against the lingual surface of an incisor, the fibers on the lingual side of the root in the occlusal third will sustain part of the strain, preventing the crown from moving labially,

FIG. 203.—Longitudinal section of the peridental membrane in the gingival portion, from a lamb (the labial gingivus).

and at the same time the fibers on the labial side of the root in the apical space will also be under strain, preventing the apex of the root from moving lingually. The general plan of arrangement which has been described is illustrated in Dr. Black's diagram made from a labiolingual section of an incisor of a young kitten (Figs. 201 and 202).

With this general plane of arrangement in mind individual sections may be studied, examining the arrangement and appearance of the fibers in detail. Figs. 203 and 204 show the labial and lingual gingivæ from an incisor of a sheep. Notice that the labial gingiva is taller and thinner, and the fibers passing up into it are not as strongly marked. Notice also the distance to which the fine fibers of the peridental membrane can be followed before they are lost in the coarser mat of gum tissue. The lingual gingiva is broader and flatter, and the fibers passing up into it form a strong and well-defined band. Under higher magnification, fibers

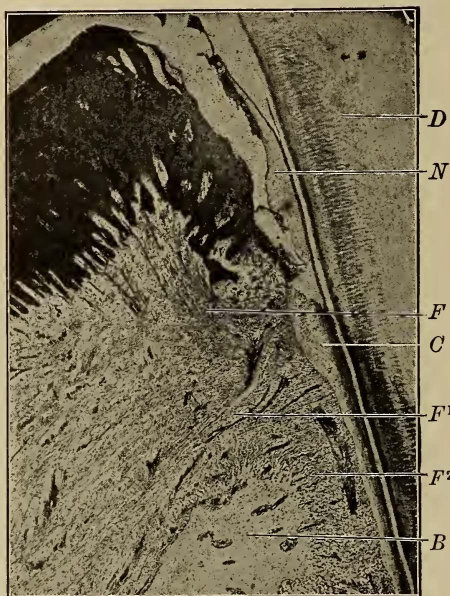


Fig. 204.—Longitudinal section of the peridental membrane in the gingival portion (the lingual gingivus): *D*, dentin; *N*, Nasmyth's membrane; *C*, cementum; *F*, fibers supporting the gingivus; F^1, fibers attached to the outer layer of the periosteum over the alveolar process; F^2, fibers attached to the bone at the rim of the alveolus; *B*, bone. (About 30 ×)

would be seen cut transversely, which pass around the tooth in the gingiva, helping to hold it closely against the enamel. In Fig. 205 the fibers uniting with the outer layers of the periosteum are very well shown. Taking transverse sections in the gingival portion and remembering that they are cut at right angles to these through the same area, the distribution of the tissues will be better understood. Fig. 206 shows a section cut close to the gingival line. At *A* the epithelium on the labial surface of the gingiva is seen, and at *B* the epithelium lining the gingival space. On the

Fig. 205.—Longitudinal section of peridental membrane of young sheep, showing fibers penetrating the cementum: *D*, dentin; *C*, cementum, showing embedded fibers; *F*, fibers running to the outer layer of the periosteum, covering the alveolar process; F^1, fibers running to the bone at the border of the process; *B*, bone. (About 80 ×)

proximal sides of the roots the fibers will be seen passing from the cementum of one tooth to that of the next. Fig. 207 is a little deeper and shows the fibers attached around the entire circumference of the root. Beginning at the middle of the labial surface, the fibers will be found springing from the cementum and passing out at right angles to it, to be lost in the fibrous mat supporting the epithelium. The fine fibers of the peridental membrane can be followed for about half the distance to the epithelium before they are lost in the coarser mat of gum tissue, and a fairly definite boundary will be seen between what should be considered peri-

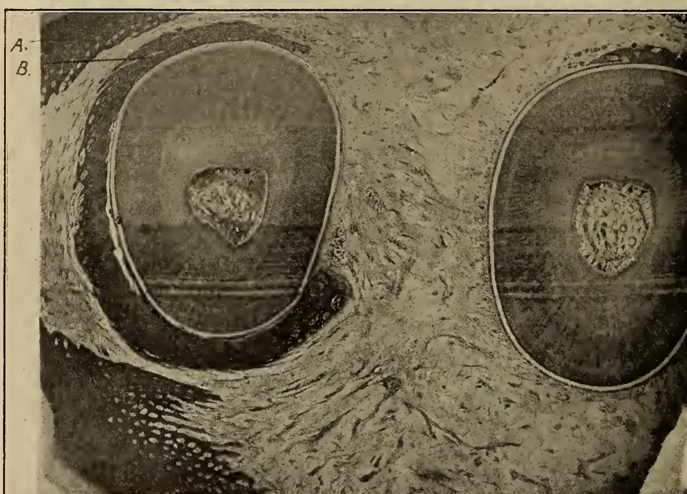
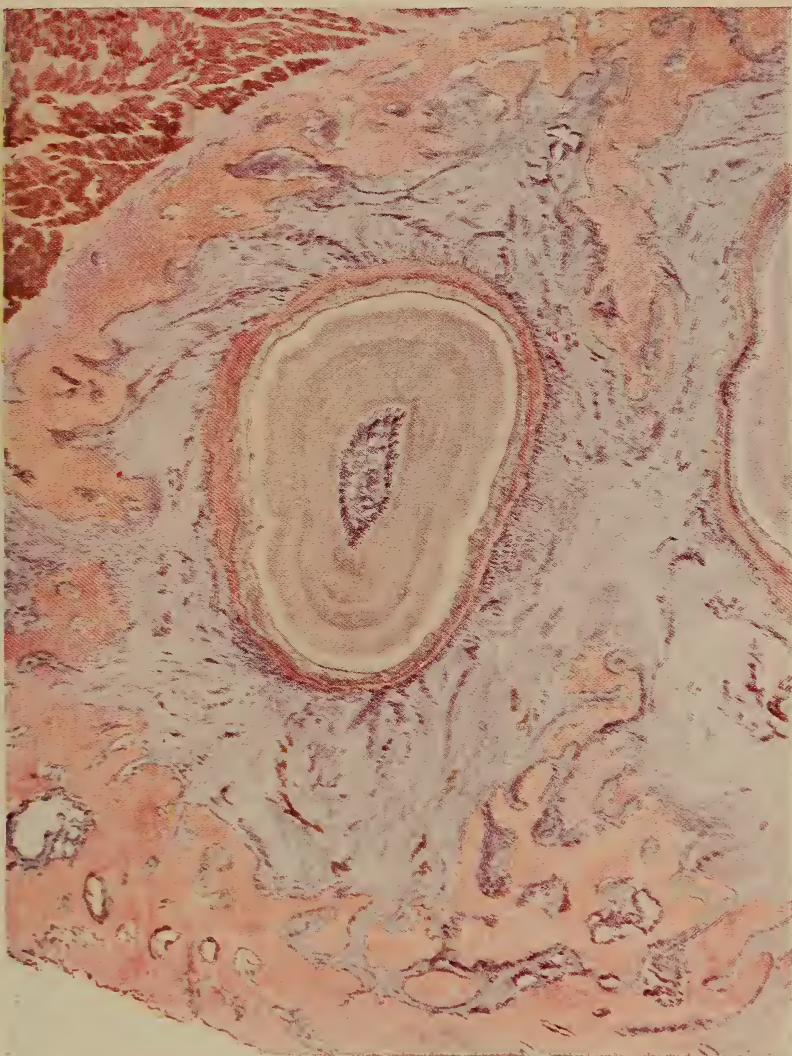


Fig. 206.—Transverse section of the peridental membrane in the gingival portion, from young sheep. The roots of two temporary incisors are cut across. The epithelium lining the gingival space is shown part way around one. *A*, epithelium on labial surface of gingivæ; *B*, epithelium lining the gingival space. (About 60 ×)

dental membrane and the gum tissue. As the distolabial angle of the root is approached, the fibers passing from the cementum tend to swing around distally, and pass to the mesiolabial angle of the adjoining tooth. Along the proximal surface the network which supports the interproximal gingivus is well shown. The fibers springing from the cementum interlace and pass around bloodvessels and fibers which are passing up into the gingiva, and finally are inserted into the cementum of the next tooth. In this way it will be seen that the teeth in the entire arch are firmly bound together by the fibers in the gingival portion. This explains the

PLATE XVI



Transverse Section of Peridental Membrane.

Stained with hematoxylin and eosin. Alveolar portion.

way in which the positions of all the teeth are affected by the loss of a single one in the arch, and the way in which the movement of one tooth will draw its neighbors after it. It also explains the separation of the central incisors when the frenum labium passes through between the teeth, and is inserted on the lingual surface of the alveolar process. If these incisors are to be held together permanently, normal attachment of fibers extending from the

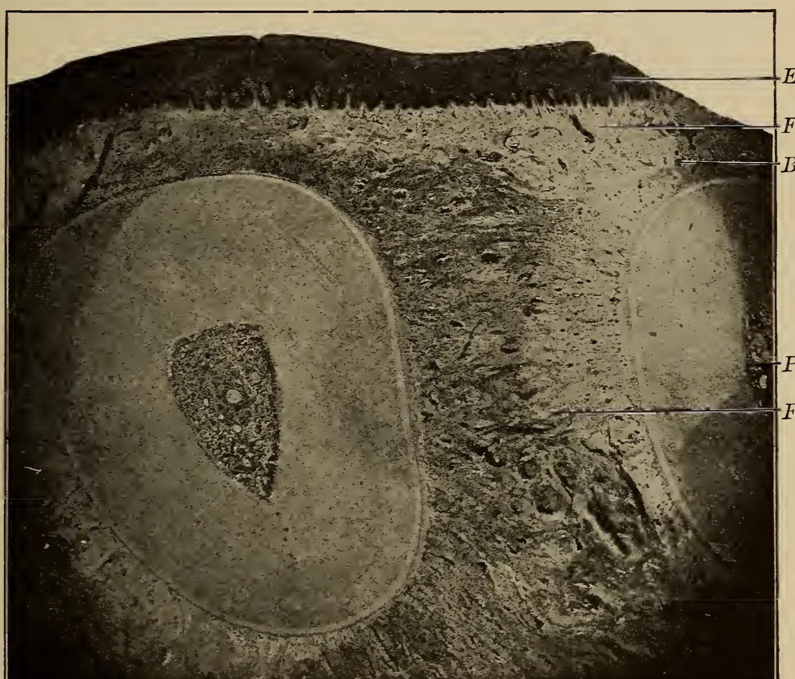


FIG. 207.—Transverse section of the peridental membrane in the gingival portion (from sheep): *E*, epithelium; *F*, fibrous tissue of gum; *B*, point where peridental membrane fibers are lost in fibrous mat of the gum; *P*, pulp; *F'*, fibers extending from tooth to tooth. (About 30 ×)

cementum of one tooth to that of the other must be secured. The fibers in this area are also well shown in Fig. 208, and it can be understood how they form foundation upon which the interproximal gingiva rests. The first step in the sagging of the interproximal gum tissue is the cutting off of the fibers from the cementum, where it bends occlusally, following the curve of the gingival line on the proximal surface.

FIG. 208.—A portion of the peridental membrane between two incisors of a young sheep, showing the fibers extending from tooth to tooth.

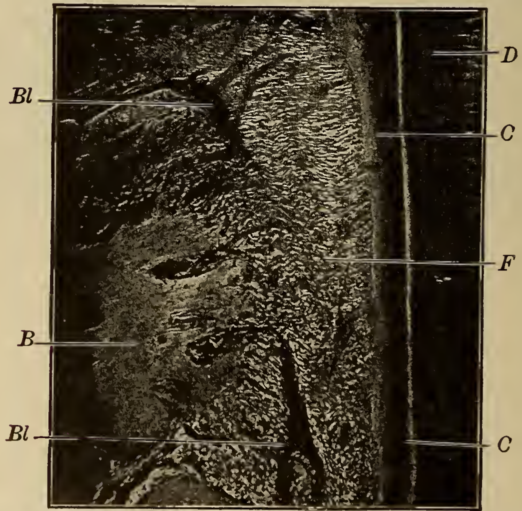


FIG. 209.—Fibers at the border of the alveolar process (from sheep): *D*, dentin; *C*. cementum; *F*, fibers extending from cementum to bone; *Bl*, bloodvessel; *B*. bone. (About 80 ×)

PLATE XVII

Transverse Section of the Peridental Membrane in the Occlusal Third of the Alveolar Portion (from Sheep).

M, muscle fibers; *Per*, periosteum; *Al*, bone of the alveolar process; *Pd*, peridental membrane fibers; *P*, pulp; *D*, dentin; *Cm*, cementum.

PLATE XVIII

Diagram of Peridental Membrane.

M, muscle fibers; *Per*, periosteum; *D*, dentin; *P*, pulp; *Cm*, cementum; *Pd*, peridental membrane fibers; *Al*, bone of the alveolar process.

Plate XVII shows a transverse section in the occlusal third of the alveolar portion from the incisor of a sheep. Upon the labial a few muscle fibers are seen and the periosteum covering the labial surface of the process. Notice the medullary spaces in the bone and the canals opening into the peridental membrane and periosteum. The light line forming the outer boundary of the dentin is characteristic. Two layers of cementum are seen, and notice the thickening of the layer where strong bundles are attached. At the middle of the labial surface the fibers pass at right angles to the cementum and are attached to the bone, but as the distolabial angle of the root is approached the bundles swing distally to be attached in the bone. In Plate XVIII, which was drawn very carefully from this section, the arrangement of the fibers is shown diagrammatically. Notice the way in which they pass over and under each other and around the bloodvessels which wind through them. This relation to the bloodvessels is important, and will be considered again later in connection with the blood supply of the membrane. The tangential fibers at the angle of the root hold the tooth against the forces which tend to rotate it in its socket. They are important in connection with all rotating movements in orthodontia. It has long been noted that rotations were the hardest movements to retain, especially if the tooth were moved in no other direction. In this case, if the tooth were turned mesially the fibers at the distolabial angle would spring the thin plate of the alveolar process as a bow is bent, leaving a condition of stress in the tissue which will tend to spring back into its old position and drag the tooth with it. Notice the greater thickness of the membrane on the lingual as compared with the labial. Figs. 205 and 209 show longitudinal sections at the border of the alveolar process. Notice that the fibers can be seen running through the entire thickness of the cementum. They are large, strong fibers and branch very little in their course. Note the bloodvessel that is shown in several of these sections, and the way in which it gives off branches passing over the border of the processes and toward the cementum.

CHAPTER XXI.

THE CELLULAR ELEMENTS OF THE PERIDENTAL MEMBRANE.

Fibroblasts.—The fibroblasts are found everywhere between the fibers which they have formed and to which they belong. They are spindle-shaped or stellate connective-tissue cells, having a more or less flattened nucleus and a body of granular cystoplasm,

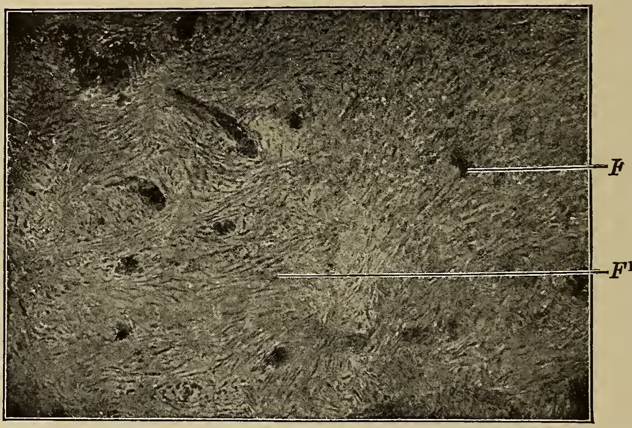


FIG. 210.—Fibers and fibroblasts from transverse section of membrane: *F*, fibers cut transversely; F^1, fibers cut longitudinally, showing fibroblasts. (About 80 ×)

which is squeezed out into thin projections between the fibers. In sections stained with hematoxylin the cells take the stain strongly and the fibers remain clear (Fig. 210). In this way the fibers are marked out by the cells which lie between them. The number of the fibroblasts in the membrane decreases with age. They are large and numerous in the membrane of a newly erupted tooth and are comparatively small and few in the membrane around an old tooth. This is, however, characteristic of fibroblasts in connective tissue generally. Fig. 210 shows a small field taken from the gingival portion of the membrane between the teeth. The magnification is low, the photograph being made with a $\frac{2}{3}$ objective. The cells are seen as little dark dots lying between the fibers, which are clear. Where the fibers are cut longitudinally they appear spindle-shaped, but where the fibers are cut across they appear star-shaped. They will be seen better in photographs made with higher magnification, but an adequate idea of their form can only be obtained by studying sections very carefully with a $\frac{1}{6}$ or $\frac{1}{12}$ objective and using the fine adjustment to gain an idea of the third dimension of space. They are shown in many of the illustrations of the epithelial structures.

Cementoblasts.—The cementoblasts are the cells which form cementum. They cover the surface of the root everywhere between the fibers which are embedded in the tissue. While these cells perform the same function for the cementum as the osteoblasts do for bone, they are quite different in form. They are always

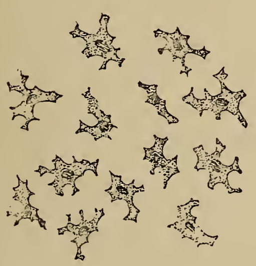


Fig. 211.—Isolated cementoblasts, showing the form of the cell as it fits around the fibers springing from the cementum. (Black.)

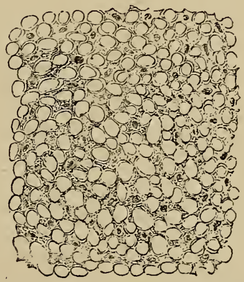


Fig. 212.—Cementoblasts as seen in a section at a tangent to the root and just missing the cementum. The fibers are left white, the cells are shaded. (Black.)

flattened cells, sometimes almost scale-like, and when seen from above, very irregular in outline. This irregularity in outline is due to the projections of the cytoplasm around the fibers as they spring from the cementum, the edges of the cell being notched and scalloped to fit about them. There is a central mass of granular cytoplasm which contains an oval and more or less flattened nucleus, from which the cytoplasm extends in projections passing partly around the fibers. Isolated cementoblasts are shown in Fig. 211, drawn by Dr. Black. In order to obtain an idea of the form of the cementoblasts, sections must be cut at a tangent to the surface of the root, and just missing the surface of the cementum. In this way the fibers are cut across and the cementoblasts are shown covering the entire surface between the fibers. These are shown in Fig. 212, in which the fibers are left perfectly clear in order to outline the cells more distinctly. In sections cut at right angles to the surface of the roots (Figs. 223, 224, and 225) the cementoblasts are shown as more or less flattened, but no idea of the way in which they fit about the fibers can be obtained.

Cytoplasmic processes extend from the body of the cementoblasts into the matrix of the cementum. These correspond to the process of the osteoblasts which occupy the canaliculi of bone. They, however, are not nearly as numerous or as regular in their arrangement as the osteoblasts. Processes extending from these cells in a direction from the cementum out into the tissue of the membrane have not been demonstrated.

Cement Corpuscles.—Occasionally a cementoblast becomes fastened down to the surface and enclosed in the matrix that is formed. They then lie in a lacuna and show processes radiating from them into the canaliculi. These correspond to bone corpuscles, but there is no such regularity of their disposition or arrangement with reference to the lamellæ, as is shown in the case of bone. In man the cementum in the gingival half of the root is usually without cement corpuscles. They often lie entirely within a single lamella instead of between two, as is the case in bone. In general they are found where the layers are thick and the embedded fibers are not specially numerous. They are very often seen where absorptions have been refilled by the formation of subsequent layers (Figs. 140 and 141).

It is by the activity of the cementoblasts producing a new layer of cementum that the fibers are attached to the surface of the root. In studying many sections, places are found where the fibers, though lying in contact with the surface are not attached to the cementum. In some places it can be seen that they have been cut off by absorptions. From a study of these layers it is evident that there is a constant readjustment in the attachment of the fibers to the root during the function of the tooth, which probably adapt it to slight changes of position resulting from wear and other conditions. It is important to remember that whenever the fibers have been stripped from the surface of the cementum, they can be reattached to it only by the formation of a new layer of cementum, building the fibers into it. This is certainly possible if the conditions are properly controlled, but the cells of the tissue must be in a normal and vitally active condition, and the surface of the root must be such that they can lie in physiological contact

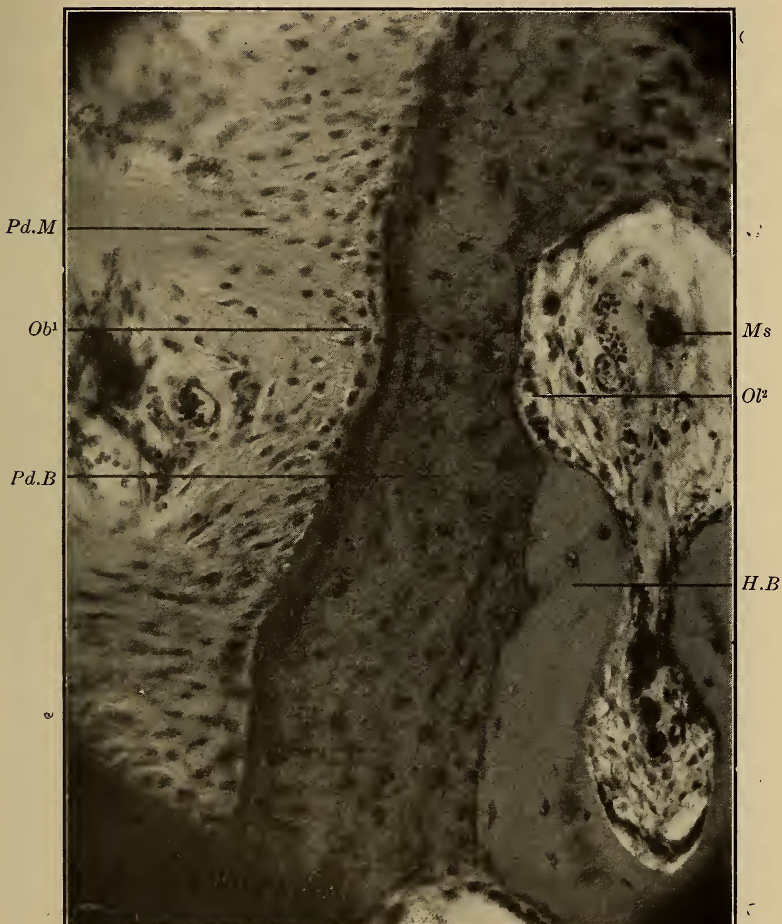


FIG. 213.—Penetrating fibers in bone. A field from Plate XIX: *Pd.M*, peridental membrane; *Ob*[1], osteoblasts of peridental membrane; *Ol*[2], osteoblasts of medullary space; *Pd.B*, solid subperidental and subperiosteal bone with embedded fibers; *Ms*, medullary space formed by absorption of the solid subperidental bone with embedded fibers; *H.B*, Haversian system bone without fibers built around the medullary space. (About 200 ×)

with it. The cure of a pyorrhea case therefore becomes a biological problem. In this connection it is important to remember that a surface of cementum which has long been bathed in pus may be so filled with poison that no cell can lie in contact with it and perform its functions.

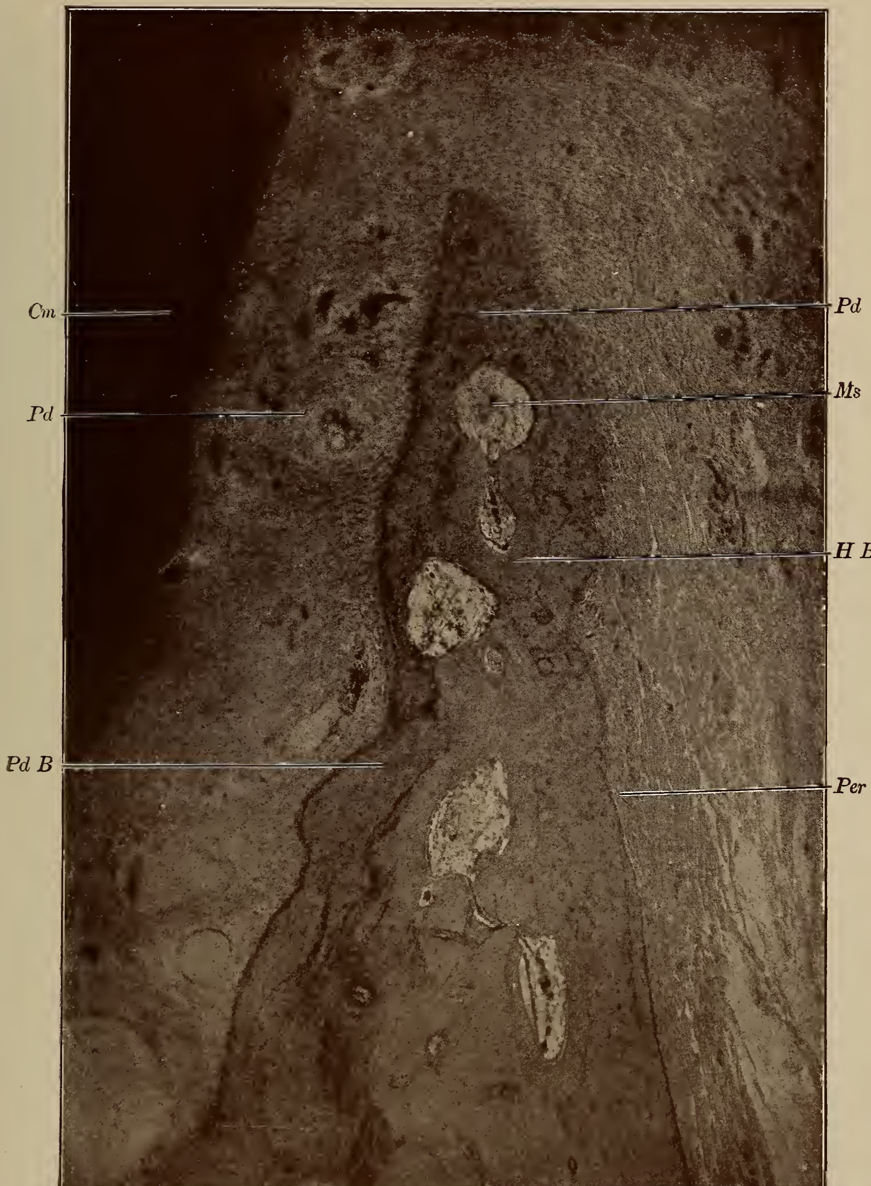
Osteoblasts.—The osteoblasts of the peridental membrane are exactly like osteoblasts in other positions. They cover the surface of the bone of the alveolar wall lying between the fibers which are embedded in it. Even in the young subject they are not found in every position, while in an adjoining area the surface of the bone may be covered with them. In the old subject they are generally absent or have been reduced to flattened scales, which are very difficult to demonstrate; but even in these cases areas will be found in which osteoblasts are present. These are areas of active bone formation. The osteoblasts lay down bone exactly as occurs in attached portions of the periosteum, but after a little thickness of this solid peridental bone has been formed it is perforated by penetrating canals, on the walls of which absorptions occur, forming spaces about which new Haversian system bone is formed. This is illustrated in Plate XIX. In this way only sufficient subperidental bone is left to furnish an attachment for the fibers.

Fig. 213 shows a higher magnification of a small area. The osteoblasts are seen between the fibers on the surface of the alveolus, and the fibers can be followed through the subperidental bone. A large absorption area has been formed which has been partly rebuilt, and the new-formed bone without embedded fibers is lighter in color. An understanding of this building and rebuilding of bone through the agency of the peridental membrane is necessary to understand the development of the face and everything in connection with tooth movement, whether physiological or artificial.

Osteoclasts.—The osteoclasts of the peridental membrane are not constant elements. They appear and disappear in response to the same conditions which lead to their appearance and disappearance in bone. They are always large, multinuclear cells, having from three or four to thirty of forty nuclei (Fig. 214). They may appear upon the surface of the cementum, upon the surface of the alveolar wall, or within the medullary spaces of the bone. They are formed from embryonal cells in the tissue in response to mechanical stimuli. Morphologically they are in no respect different from the osteoclasts in bone.

The osteoclasts are tissue destroyers and are the active agents in the removal of any hard tissue. There is no difference in them, whether they are destroying the fibrous tissue, bone, cementum, or dentin (Fig. 215). In order for them to act, their cytoplasm

PLATE XIX



Border of Growing Process.

Cm, cementum; *Pd*, peridental membrane; *Pd B*, solid subperidental and subperiosteal bone with embedded fibers; *Ms*, medullary space formed by absorption of the solid bone; *H B*, Haversian system bone without fibers; *Per*, periosteum. (About 50 X.)

must lie in actual contact with the surface to be attacked. They do not first decalcify and then remove, but apparently by applying their cytoplasm to its surface the cells destroy the intercellular substance, forming hollows in the surface, into which the cells sink. These hollows have been called Howship's lacunæ. The cells usually appear in groups and spread out over the bone or cementum to be attacked, but sometimes only two or three will

Fig. 214.—Osteoclast absorption of bone over permanent tooth: *Oc*, osteoclasts; *B*, bone of crypt wall; *F*, fibrous tissue of follicle wall; *A*, ameloblasts. (About 62 ×)

be found at a point on the surface of the bone, and these will burrow into the substance, forming a penetrating canal running through the bone (Figs. 216 and 217). In these positions the osteoclasts are usually comparatively small. As fast as the canal is formed the embryonal cells of the membrane multiply and grow into the space and at any point where absorption is going on the portion destroyed is immediately replaced by embryonal connective tissue.

This will be noted in all the illustrations showing absorptions.

Whenever absorption is going on formation is also going on in an adjoining area. In this way the function of the tissue is maintained until the last remnants of it are destroyed. The general statement may be made that bone formation is always accompanied by bone destruction, and bone destruction by rebuilding. The result depends

Fig. 215.—Osteoclasts in cancellous bone near the peridental membrane; in some portions of the field osteoblasts are seen. As bone is removed note how embryonal connective tissue replaces it.

upon which side the balance swings. The alternation of formation and absorption in the removal of hard tissues is well illustrated in the absorption of the roots of the temporary teeth. The absorption does not begin at one point and spread continuously over the entire surface of the root. If it did so, all of the fibers would be

FIG. 216.—Osteoclast absorption forming penetrators of canal: *a*, bone matrix; *b*, bloodvessel; *c*, embryonal connective tissue; *d*, new bone formation; *e*, osteoblasts; *f*, osteoclasts. (Black.)

FIG. 217.—A longitudinal section through the remains of the alveolar process around the root of a temporary tooth about to be shed (sheep): *C*, the cementum on the remains of the tooth; *B*, penetrating canals cut through the labial plate of bone.

cut out and the tooth would drop off with at least a considerable portion of the root. The process progresses in something of this

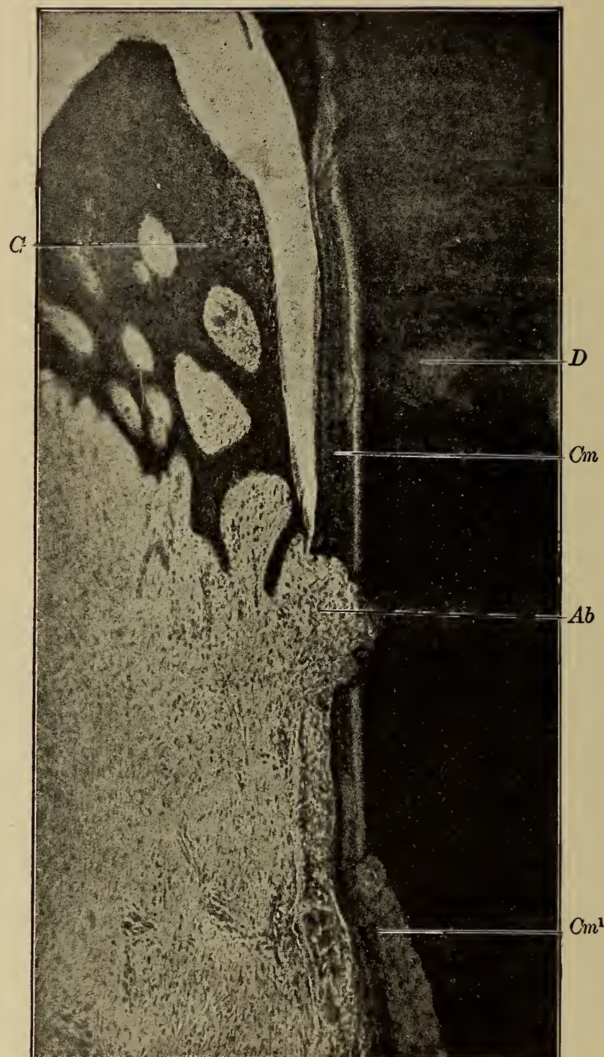


Fig. 218.—Root of a temporary incisor, showing absorption and rebuilding of cementum (from sheep): *G*, gingivus; *D*, dentin; *Cm*, cementum; *Ab*, absorption cavity, showing Howship's lacunæ; Cm^1, new-formed cementum. (About 50 ×)

fashion: At a point on the side of the root near the apex, where the growth of the erupting tooth produces pressure, osteoclasts appear in the membrane, cutting off the fibers, displacing the cementoblasts, and arranging themselves in groups on the surface of the root. These dissolve away the cementum and sink into the tissue, perhaps cutting into the dentin for a short distance. By this excavation the pressure is relieved, the osteoclasts disappear, cementoblasts are formed in the embryonal connective tissue,

FIG. 219.—A transverse section through an incisor from the same jaw as Fig. 218, and at the level of Cm^1, showing the refilling of the absorption cavity by new layers of cementum.

and the deposit of cementum begins in the excavation, reattaching the fibers in this area. As the rebuilding progresses, at a point a little farther occlusally, osteoclasts appear and begin a new excavation. In this manner the process continues. When the absorption stops in the second point, it begins again at the first, cutting much deeper into the dentin, and, oscillating back and forth, it progresses until all of the dentin may be destroyed, leaving the hollow cap of enamel, and even then new-forming cementum to maintain the attachment will be found around the circumference. In this way it will be seen that the function of the tooth is maintained until its successor is ready to take its place in a very short time. The importance of this arrangement will be more fully appreciated after a study of the relation of the teeth to the development of the face. Fig. 218 shows a longitudinal section through a temporary incisor of a sheep. At *Ab* an absorption has just been completed, for the osteoclasts have disappeared. The excavation is seen filled with embryonal tissue and rebuilding is about to begin. At *Cm* an older and much larger absorption space is seen which has been partially replaced by a formation of new cementum reattaching fibers. In Fig. 219 a transverse section of the root is seen which is from the same jaw cut at the level of *Cm,* and shows the absorption refilled. This patchwork performance goes on in the same way in the bone of the alveolar process, and its study is one of the most interesting phases of the relation of the teeth to the development of the face. Without a clear idea of this it is impossible to understand how the teeth, after their roots are fully formed, can move through three dimensions of space and retain their function all the time.

Epithelial Structures.—The epithelial structures of the peridental membrane were first described by Dr. Black in his volume *Periosteum and Peridental Membrane,* published in 1887. At this time Dr. Black considered them to be of lymphatic character and named them endolymphatics. His conception of them was that they were lymphatic channels crowded with adenoid cells. Since then the form and appearance of the cells and the character of their reaction with staining agents has shown the cells to be of epithelial character. In the same year that Dr. Black's book was published, von Brunn[1] described the same structures. He considered them as epithelial remains of the outer layer of the enamel organ, growing down around the root beyond the gingival line where the formation of enamel stops. It has seemed probable to the writer that this was correct, but their histogenesis has not been sufficiently well followed, and it presents an attractive field for research. These structures undoubtedly originate from the epithelium of the enamel organ, probably both of the outer and inner layers. In the authors' opinion they have an important relation to the formation of cemen-

[1] Archiv f. Anatomie, 1887.

tum which accounts for their persistence in the membrane. While they are derived from an embryonal structure, the enamel organ, it does not seem proper to regard them as embryonal remains, for while, like all the cellular elements, they are more numerous in young people than in old, they are persistent throughout life. They have been shown in the membrane from a man aged seventy years, and it does not seem logical to suppose that embryonal debris that was useless to the organism would persist through life. Up to the present time, however, nothing has been discovered about these structures to throw any light upon their function. The author has long been of the opinion that they were related to the formation of cementum but this is not sufficiently established to be more than suggested here. Specimens have strongly indicated that they were important in some pathologic conditions. Their cells have been found dead and degenerating in pathologic material beyond the point showing any pathologic condition in other cells. These structures have been observed in sections from man, sheep, cat, dog, and monkey. The best material for their study is a young sheep or pig.

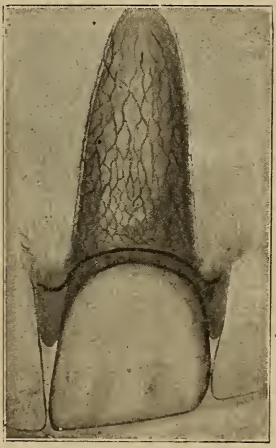


Fig. 220.—Diagram of glands of peridental membrane. (Black.)

Distribution.—These structures are composed of cords or rows of epithelial cells, surrounded by an extremely delicate basement membrane (Fig. 220). In some cases there is a slight indication of a circular arrangement of connective tissue around them. The cords lie very close to the surface of the cementum, winding in and out among the fibers (Fig. 221). They anastomose and join with each other, forming a network the meshes of which are comparatively close in the gingival portion (Fig. 222), and comparatively wide in the apical portion, the cords becoming scarcer as the

Fig. 221.—A section cutting diagonally through the root, showing the network of epithelial cords, *A*; dentin, *D*; cementum, *Cm*.

apex of the root is approached, but the author has seen them in sections from the apical third.

A binocular microscope was used to obtain a true conception of the way in which these cords wind in and out among the bundles of fibers. The cords show a marked tendency to run out into the membrane and loop back (Fig. 223), coming very close to the surface of the cementum.

The ends of the loops toward the cementum often show enlargements which in some cases apparently lie directly in contact with the cementum (Figs. 224 and 225). These enlargements next to the cementum are shown in Fig. 223.

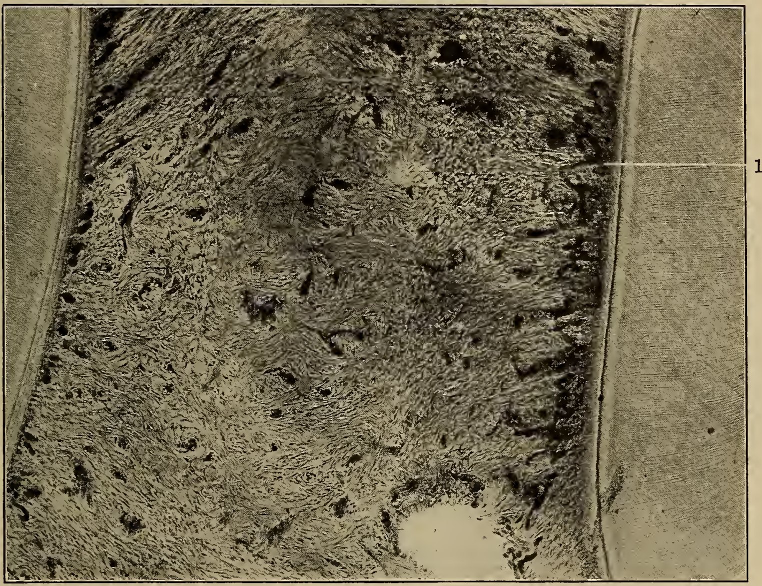


Fig. 222.—Transverse section of the peridental membrane in the gingival portion, showing the position of the epithelial cords. At *1* the loop shown in higher magnification in Fig. 224 is seen.

The Arrangement of the Cells.—There is no definite arrangement of the cells in these cords. In some places there will be a ring of irregular polyhedral or rounded cells which almost exactly resemble a simple tubular gland. In other places there is a pretty definite outer ring of cells and a central mass enclosed by them. The cells are made up of granular cytoplasm, each containing an *ovoid* nucleus that is rich in chromatin. The author has spent much time attempting to work out the relation of these cords to the epithelium lining the gingival space, thinking that possibly they open into it. In a few places structures appearing very much like a duct have been seen, as shown in Fig. 227, but they are apparently only unusually large cords. There is no regularity in places where they are found, and no connection with the gingival space has ever been discovered. Toward the gingival, as the gingival line is approached, the cords seem to swing out away from the cementum, especially on the proximal side, and to pass up into the gingivæ, where they are lost among the projections of the epithelium.

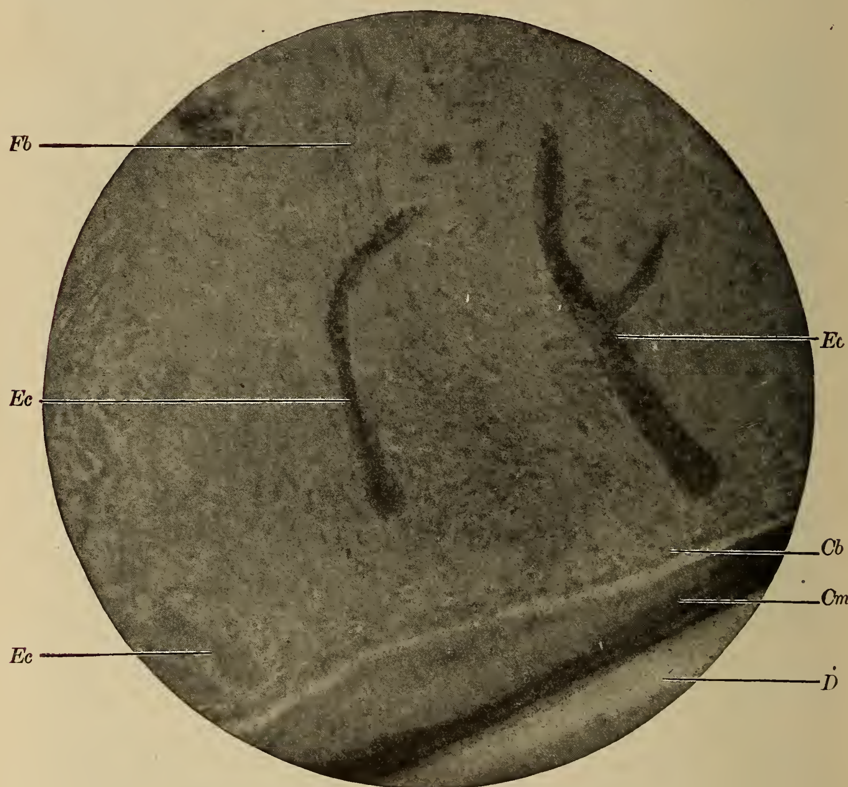


Fig. 223.—Epithelial structures of the peridental membrane (from sheep): *Fb*, fibroblasts; *Ec*, epithelial structures; *Cb*, cementoblasts; *Cm*, cementum; *D*, dentin. (About 468 ×)

Gland of Serres.—Salter, in his *Dental Pathology and Surgery,* quotes Serres, who assigns the function of a gland to the epithelium lining the gingival space. This, the writer believes, is the first reference to an appearance in the tissues that has been called the gland of Serres. It has long been noted that the epithelium lining the gingival space was lighter in structure, composed of larger cells, and had no horny layer on its surface, as is true of the epithe-

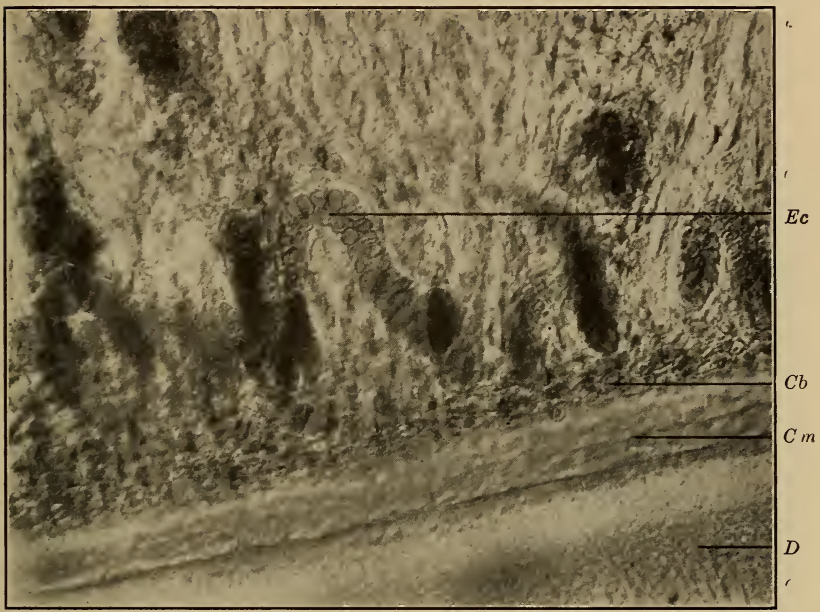


FIG. 224.—Epithelial structures: *Ec*, epithelial cord, apparently showing a lumen; *Cb*, cementoblasts; *Cm*, cementum; *D*, dentin. This loop is seen in Fig. 209.

FIG. 225.—Transverse section, showing the cellular elements. (About 900 X)

lium on the outer surface of the gingivus. Upon the proximal surfaces the projections of the epithelium which extend down between the papillæ of connective tissue, which constitute the stratum papillaris, are specially long, and in the connective tissue between them collections of small round cells are often found. It is between these projections of epithelium that the cords of epithe-

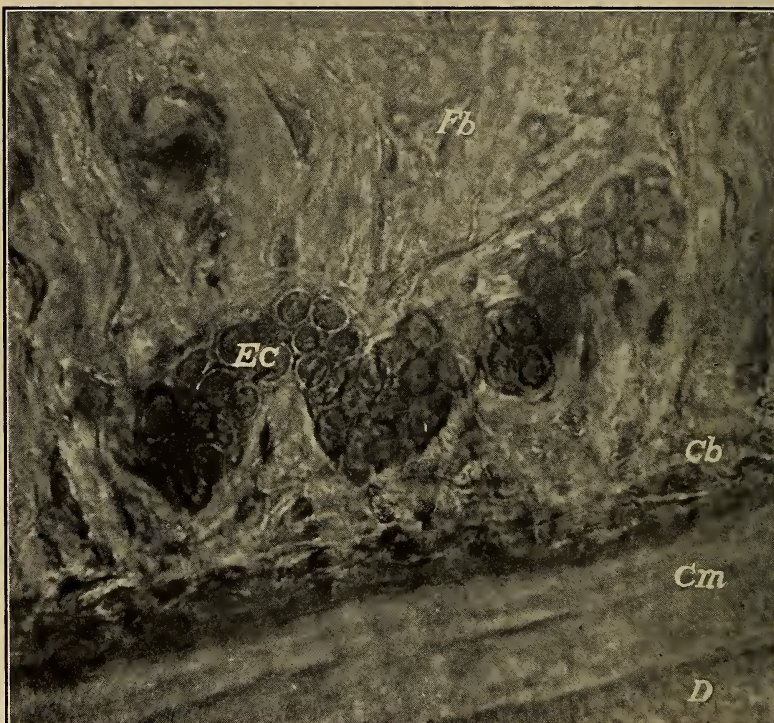


Fig. 226.—Epithelial structures (from sheep): *Fb*, fibroblasts; *Ec*, epithelial structures; *Cb*, cementoblasts; *Cm*, cementum; *D*, dentin. (About 700 ×)

lial cells which have been described are lost, and to this portion of the tissue Dr. Black has again called attention, as the gland of Serres. Sufficient work has not yet been done upon this subject to know whether this is a constant arrangement, or whether it is found only in certain animals, or even whether it may not possibly be pathologic. The appearance is shown in Figs. 228 and 229. The work of the last five years has convinced the writer, that this appearance is the reaction of the tissue to infection. One of the important functions of the supporting tissues about the necks of the teeth is to resist and remove infection, and all the structural elements of the tissue are arranged for that function. The epithelium, the connective-tissue fibers, the capillary bloodvessels, the lymphatics, and the cellular elements of the connective tissue, are so arranged as to immediately respond to an invasion of infecting organisms in such a way as to destroy and remove them if possible.

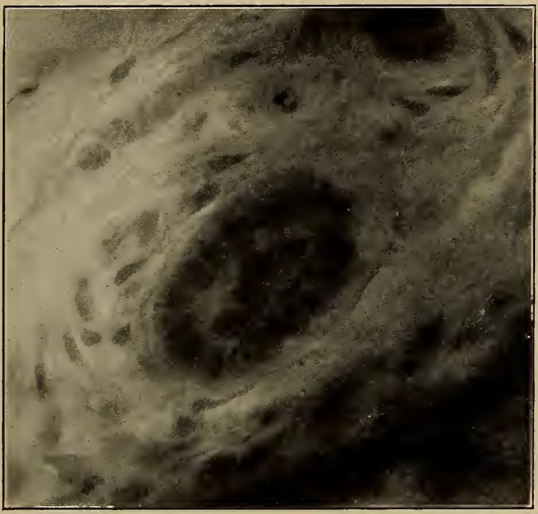


Fig. 227.—A very large cord which was at first mistaken for a duct.

Bloodvessels.—The peridental membrane possesses a very rich blood supply. A number of vessels enter the membrane in the apical portion from the medullary spaces in the bone. Some of these, passing through canals in the apex of the root, supply the dental pulp, others pass up through the membrane. As they extend occlusally they give off and receive branches which enter the membrane from the bone of the alveolar wall. In this way the caliber of the principal vessels is maintained throughout their course in the membrane. As they reach the border of the alveolar process they give off branches which anastomose with the vessels of the periosteum and gum tissue.

In the young membrane these vessels occupy a position closer to the bone than the cementum, and as the membrane becomes thinner they often come to lie in grooves in the bone. Vessels of any size are rarely seen close to the cementum, and the capillaries in the membrane are rather scarce, though they are more numerous than

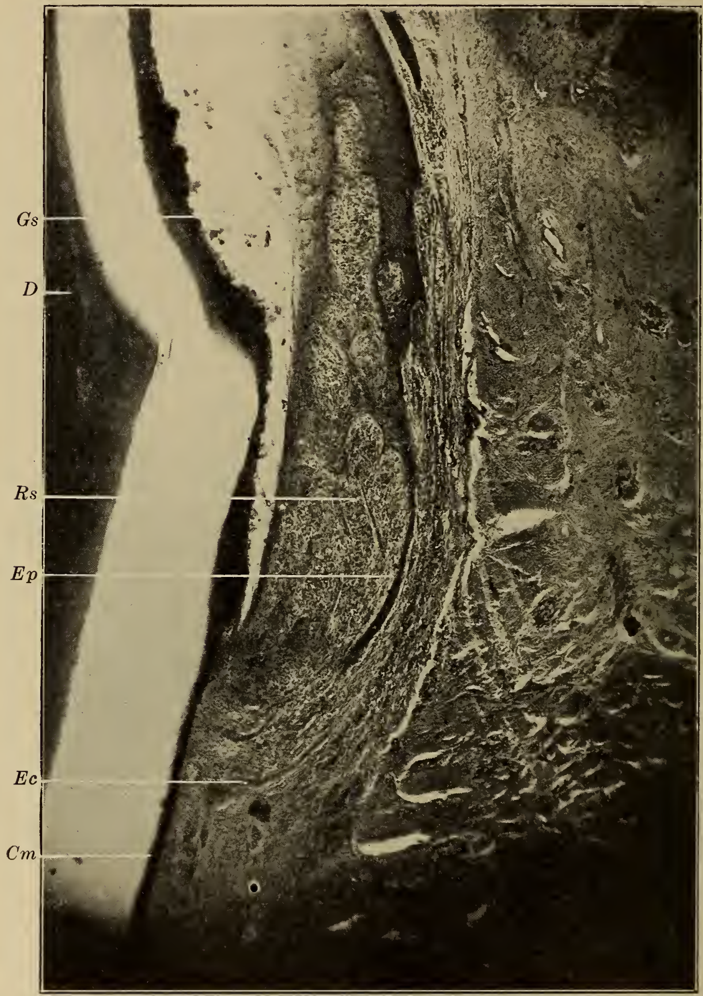


FIG. 228.—Longitudinal section, cut mesiodistally: *D*, dentin; *Cm*, cementum which has separated from the dentin; *Gs*, gingival space; *Ep*, epithelial projection from the lining of the gingival space; *Ec*, epithelial cords; *Rs*, small round cells in the connective tissue.

in most connective tissues of as compact a character. The anastomosis of the vessels in the membrane is quite rich. It is important to remember that the cancellous bone of the process is richly supplied with bloodvessels, and the anastomosis with the vessels of the membrane, from the alveolar wall and over the border of the process, is important in the consideration of pathologic condi-

Fig. 229.—A longitudinal section cut mesiodistally: *E*, epithelium of the gingivus; *Gs*, gingival space; *Cm*, cementum which has separated from the dentin; *Ec*, epithelial cords.

tions. In alveolar abscess the vessels entering through the apical space may be entirely cut off, but this does not disturb the blood supply of the rest of the membrane. The removal of the pulp has often been advocated in the treatment of pathologic conditions of the membrane, on the ground that the vessels entering the pulp rob the membrane of blood supply, and that their removal made recovery more certain. No one having a knowledge of the blood supply of the membrane could advise this for that reason.

In their course through the membrane the vessels wind between the principal fibers in a way that can only be appreciated by studying sections with a binocular instrument, and when this condition is realized it can be understood how some inflammations in the membrane are set up. For instance, when force is applied to a tooth, the principal fibers are stretched. This causes them to close some spaces and open others. The vessels in the closed spaces are constricted and the flow of blood through them partly shut off. The vessels in the enlarged spaces dilate to compensate. If the force is removed, the dilated vessels are again constricted, and the constricted ones enlarged, and the result is a literal sawing upon the walls of the bloodvessels which in a very short time will set up an acute inflammation. This is extremely important in the application of force in orthodontia, and often also in the use of the mallet in condensing gold, especially for young patients.

Lymphatic Vessels.—The lymphatics of the peridental membrane have been described in Chapter XIV. The writer was first convinced of their presence in the membrane by a study of the manner of extension of destructive inflammations of the peridental membrane and they were afterward demonstrated by injection. The collecting vessels from the labial, buccal and lingual surfaces of the gums and gingivæ pass outside of the periosteum of the alveolar process to the wreath of collecting trunks at the reflection of the tissues from the surface of the bone to the lips or cheeks on the outside and to the collecting trunks of the floor of the mouth and palate on the inside. The collecting vessels from the papillæ lining the gingival spaces penetrate the ligamentum circulare very close to the cementum and extend in the interfibrous tissue accompanying the bloodvessels and nerves, through the peridental membrane as far as the apex of the root, where they anastomose with the efferent vessels from the dental pulp. They have been followed through the bone to the infraorbital canal and the inferior dental canal emerging from the corresponding foramina and passing to the lymph nodes of the submaxillary group. Injected vessels in the peridental membrane are shown in Fig. 230.

Nerves.—The nerves of the peridental membrane enter the peridental membrane in company with the bloodvessels. Their source is the same as that of the bloodvessels. The trunks entering in the apical space contain from eight or ten to fifteen or twenty medullated fibers. Some of these enter the dental pulp, others extend up through the membrane, winding in and out among the fibers, generally following the course of the bloodvessels. Many trunks containing eight or ten fibers enter through the alveolar

Fig. 230.—Transverse section of the peridental membrane; showing injected lymphatic vessels (oc., 3; obj., 16 mm.; reduced about one-tenth).

wall. In this way a fairly rich plexus is formed, from which fibers are continually given off to be lost in the tissue. They probably terminate in beaded free endings. No special nerve endings have been demonstrated. A few Pacinian corpuscles have been seen near the gingival border. These are not generally found, however. The nerves of the membrane give to it the sense of touch, which is the only sensory function of the membrane. As has been noted in connection with the dental pulp, the hard tissues and the pulp have no sense of touch. The contact of any substance with the surface of the tooth is reported to consciousness through the medium of the peridental membrane. For instance, the slightest touch of a delicate instrument produces a slight movement of the tooth which affects the nerves between the fibers. The delicacy of this mechanism can be demonstrated by the following experiment. Lightly touch the surface of the enamel and the patient will tell at once not only which tooth is touched, but whether a steel instrument or a wooden point or some soft material was used. If, however, the finger is placed upon a surface of the tooth and firm pressure made in one direction, the contact of the point will not be recognized.

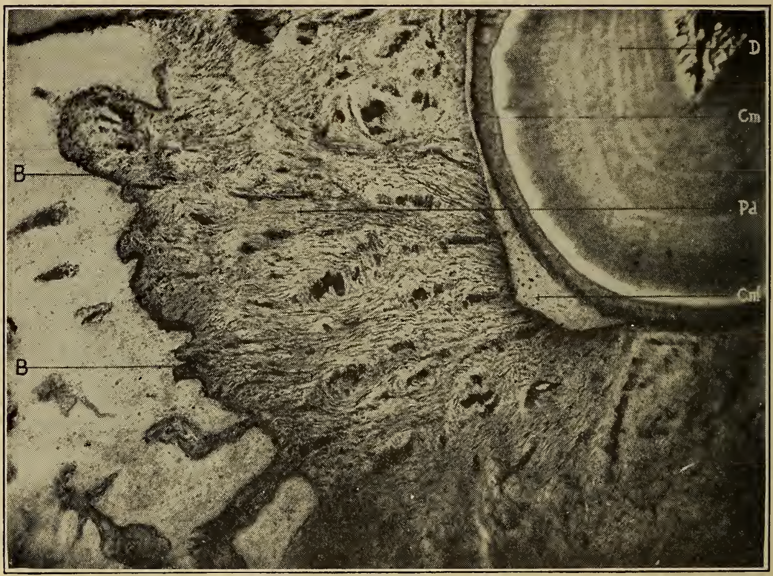


Fig. 231.—Young membranes (from sheep): *D*, dentin; *Cm*, cementum; *Cm*[1], thickening of cementum to attach fibers at the corner; *Pd*, peridental membrane; *B*, bone forming the wall of the alveolus. (About 80 ×)

The Changes in the Peridental Membrane with Age.—The teeth are formed in crypts in the bone, and when they begin to erupt the roof of the crypt is removed by absorption, making an opening large enough for the crown to pass. As the root is formed, the tooth moves occlusally and the alveolus grows up around it, beginning at the margins of the crypt. When the tooth first erupts, therefore, the alveolus is much larger than the root, and the fibers of the peridental membrane are very long. The size of the alveolus is reduced by the formation of bone, by the osteoblasts on its wall, and the size of the root is increased by the formation, layer after layer, on its surface. In this way the thickness of the membrane is reduced. Figs. 231 and 232 were made to illustrate this change. They were photographed with as nearly the same magnifications as possible, so as to compare the thickness of the layers. In the first, there are but two layers of cementum; notice the thickening of the last-formed layer, to attach the strong bundles of fibers at the angle of the root. The second is from a temporary tooth which has been in position and function for a long time; notice the thickness of the cementum and that the formation of bone and cementum

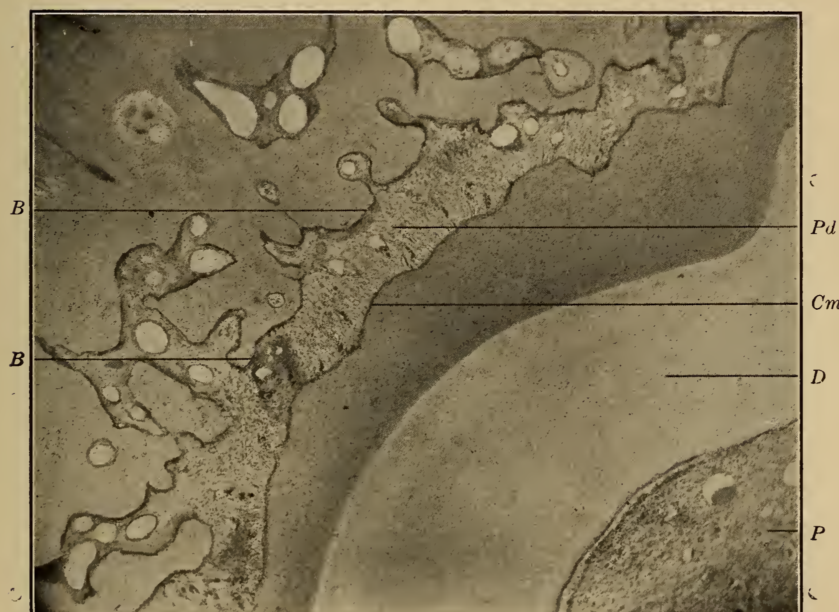


Fig. 232.—Old membranes (from sheep): *D*, dentin; *Cm*, cementum; *Pd*, peridental membrane; *B*, bone forming the wall of the alveolus; *P*, pulp. (About 80 ×)

has reduced the thickness of the membrane to not more than one-third of its original amount. Notice also that the surface of both bone and cementum are not even, but scalloped, and that where the cementum projects toward the alveolar wall there is a depression in the bone, and where the bone projects toward the cementum there is a depression in the cementum. There is therefore a distinct tendency for the two tissues to interlock but remain separated by a layer of fibrous tissue. The author has never seen a specimen showing a union between calcified substances of bone and cementum. Two surfaces of cementum may become united by direct calcification and the teeth fused together. This is illustrated in many freak specimens to be found in any dental museum. It is often stated that a tooth had become ankylosed to the bone, but to the author's knowledge no specimen has ever been shown in which the separating layer of fibrous tissue was not present.

Practical Consideration.—These structural facts are of the greatest practical importance, especially in the making of gold fillings for young persons. Every operator has noticed the greatest difference in the feeling of the instrument under the mallet upon different teeth. In one instance it will ring under the steel mallet as if the tooth were resting on an anvil; in another case it feels as if the tooth were resting on a cushion. In the first case all of the force of the blow is expended in the condensation of the gold. In the second, a large proportion is lost in the movement of the tooth. If the membrane is thin and the cementum and bone are interlocked, the tooth is firmly supported. If the membrane is thick and the fibers long, as in the first illustration, the blow is dissipated in the sag of the fibers. The tooth is jumping up and down in its socket. The force used is dissipated, the gold is not condensed, and in a very short time an acute inflammation is set up and the tooth becomes very sore to the blows. This the author believes is the explanation of the idea that gold will not preserve teeth for young children. It has often been said that children's teeth are too soft for gold fillings. The difficulty is not with the enamel and dentin, but because of the thickness of their membranes. The gold is not sufficiently condensed to exclude moisture, and the fillings fail. Serious damage also may be done to the membrane. The Museum of the Northwestern University Dental School contains an object lesson on this point. It consists in a bicuspid with a beautifully condensed and finished gold filling in a mesial occlusal cavity. The history accompanying it is somewhat as follows: The operation was undertaken for a patient aged about fourteen years. The tooth became exceedingly sore under the mallet; the filling was, however, completed and polished, but a few days later the tooth was picked out with the fingers. The peridental membrane had been literally hammered to death. Stated in scientific terms, the fibers had sawed upon the bloodvessels, exciting an acute inflammation, resulting in complete stasis and the death of the tissue. In all operations where gold is to be condensed in teeth with thick membranes, they must be firmly supported so as to be held rigidly against the blow.

CHAPTER XXII.

ABSORPTION OF TEETH

By NEWTON G. THOMAS, M.A., D.D.S.

The absorption of teeth implies a phenomenon which is known to occur in both dentitions. To the primary dentition, absorption is a part of normal history; with the permanent dentition, it is associated only with unrecognizable and inexplicable conditions or strictly pathological agencies. Hence our first classification of absorption is physiological and pathological. Under the former comes the removal of temporary tooth roots and the roots of implanted teeth, while under pathological comes the removal of permanent tooth roots, either wholly or in part. These occurrences form the ground work of this discussion.

Fig. 233.—Showing normal absorption of a temporary molar without pressure from a permanent successor.

Various causes of the absorption of the roots of temporary teeth have been presented. The principle ones ascribed are pressure, the ectodermic origin of enamel, blood-pressure, the gubernaculum dentis, and the deposition of bone impelling the permanent teeth occlusally. It is urged that the pressure of the erupting permanent teeth instigates the process whether one or all of the causes of eruption mentioned begins or maintains the movement. It is a common observation that the pressure of permanent teeth sometimes fails to stimulate absorption and again it is seen that temporary teeth often absorb when their permanent successors are absent (Fig. 233).

The absorption of the roots of the temporary teeth must be considered as Tomes considered it, a physiological or vital process, which all of the factors named may abet but do not explain.

The agent of absorption presents an interesting but unfinished study. Kölliker designated the multinucleated giant cell, the osteoclast, almost always seen in areas where osseous tissue is in process of formation, the agent of tissue removal, because bone building is always a composite of construction and destruction, a condition not seen in tooth tissues because changes similar to those in bone do not take place. Once teeth are formed they do not change form: areas of their surfaces may be removed but it is never done for the purpose of reconstruction as is the case when subperiosteal bone is removed to give place to Haversian system bone. Where, however, teeth are being physiologically removed osteoclasts are found without fail. Until quite recently this cell maintained its designation as a tissue destroyer undisputed, but at the present time its function is held in question. It is stated that there is no positive evidence that the osteoclast is active in destroying bone. The explanations given are that they are degenerate osteoblasts that have become confluent,[1] or that have been affected by the agency that is affecting the bone, and, therefore, are in a condition of degeneracy.[2] Also destruction of bone by halisteresis as in osteomalacia is mentioned to prove that cells are not necessary to its accomplishment.[3] Both of these hypotheses are unsatisfactory. Sections can be readily produced in which osteoclasts show no evidence of disintegration and in which there is no evidence that they are the products of osteoblastic fusion. In fact cementoblasts, the analogue of osteoblasts, are noticeably absent from the surfaces of teeth on which absorption is in progress.

The origin of osteoclasts is controverted as much as their function. Prentiss, Jackson and Dautschakoff state that they are derived from the reticular cells of marrow. Kölliker, Bredichin, and Howell suggest that they are osteoblastic in origin, the osteoblast in response to some unknown stimulus fusing with its fellows to assume a new function. Wegener, Schaffer,[4] Fischer,[5] and Mallory[6] trace them to

[1] Arey: The Origin, Fate and Significance of Osteoclasts, Tr. Chicago Path. Soc., pp. 231–234.

[2] Stöhr: Text-book of Histology, pp. 68 and 202.

[3] Loc. cit.

[4] Prentiss: Origin and Fate of Osteoclasts, Surg., Gynec. and Obstet., 1915, xx, 678.

[5] Anatomische Hefte, 1909.

[6] Principles of Pathology, 1912, p. 52.

endothelial cells, while Ranvier, Duval, and Bohm[1] assert that they arise from lymphoid marrow cells. In the consideration of the internal absorptions seen in dentin, Causch[2] avers that they are the products of odontoblasts, as does Salter also. To this Causch adds that tissue destruction does not depend upon them, as phagocytic leukocytes may produce the same results. In this it will be observed he harmonizes closely with Mallory. The specimens from which the accompanying figures are made also testify to the endothelial origin of the osteoclast. Fischer's assumption that the endothelium of capillaries may destroy tissue is also closely related to Mallory's statement.[3] Bland-Sutton,[4] in 1887, described giant cells formed by the fusion of phagocytes, and adds: "The large multinuclear osteoclasts seen in places where vertebrate bone and teeth are under absorption must also be placed in the same category." In accord with the foregoing, Mallory says: "When an endothelial leukocyte finds difficulty in dissolving a substance, as, for instance, lime or certain fat products or the blastomyces, it frequently fuses with other endothelial leukocytes to form a multinucleated mass of cytoplasm commonly termed a foreign body giant cell. If the foreign body is too large for one leukocyte to incorporate (cholesterin crystals, hairs) one or more giant cells are formed which surround it or plaster themselves to its surface."[5] With this Delafield and Pruden agree.[6] It is quite certain that the osteoclast is not the product of mitosis, as Kölliker thought, without cytoplasmic division as mitotic figures are never seen in it.

In the sections which formed the basis of this study irregular foveolæ are seen in which are groups of cells apparently of leukocytic origin, which to all appearances are active in the removal of calcified tissue, while on the surface continuous with that on which they work, are multinucleated cells in great numbers filling smoothly formed spaces. This condition may be explained by the interpretation of Sutton, Causch and Mallory. The phagocytic endothelial cells introduce the process of tissue removal and later fuse, according to Mallory's hypothesis, continuing the destruction of tissues after their fusion, thus forming the smooth bay-like excavations noted. This also explains the low number of giant cells found in the early

[1] Loc. cit.
[2] Transactions of World's Columbian Dental Congress, p. 114.
[3] Mallory: Principles of Pathology, 1912, p. 52.
[4] Introduction to General Pathology, 1887, p. 124.
[5] Mallory: Principles of Pathology, 1912, p. 52.
[6] Text-book of Pathology, p. 119.

stages of endochondral bone formation, which point is mentioned by Stöhr[1] and emphasized by others. Phagocytic endothelial cells or other means of calcified tissue removal may be employed. To the writer it seems conclusive that Mallory's assumption is correct.

The procedure of tissue removal is difficult of explanation. To the present time it has not been determined that osteoclasts or phagocytic leukocytes produce acid for this purpose. Also the process is more than decalcification. In decalcification we know that certain tissues resist acid for varying periods of time. In the process under discussion we have complete tissue removal, the connective-tissue matrix of the calcified structures and the dense peridental membrane

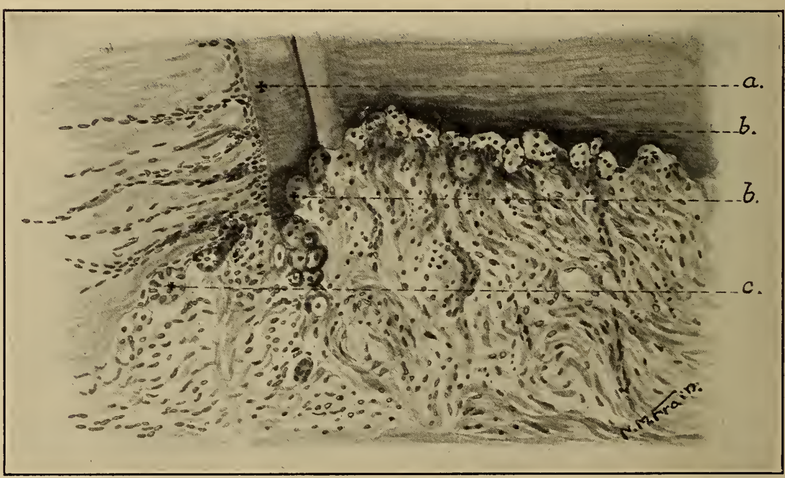


Fig. 234.—Section showing absorption of the tooth of a sheep: *a*, cementum; *b*, osteoclasts in cementum and dentin; *c*, osteoclast in the peridental membrane.

as well (see 234, *c*). In connection with the endochondral bone formation it has been suggested that reduction of blood supply causes autolysis of cells in the cartilaginous matrix and a consequent dissolution of the calcified cartilage spicules by the enzymes set free. In the light of the foregoing the last hypothesis seems unnecessary. It is commonly accepted that osteoblasts may become osteoclasts because it is known that cells long inactive may change their function, or that connective-tissue cells, under changed conditions, may develop specializations, or cells long inactive may resume functional activities of a different character from that carried on in

[1] Text-book of Pathology, pp. 68 and 202.

their earlier histories. Thus liberated cartilage or bone corpuscles may become cartilage or bone builders. By injecting lamp-black or bacteria into the subarachnoid space Weed[1] found that connective-tissue cells became phagocytic and ameboid. Hassin[2] found that glia cells did similarly, devouring myelin and migrating to the vessels of the area as did Nissl and Altzheimer.[3] Similar phenomena have been observed by various workers on other tissues and organs.

At birth the jaw contains all the deciduous teeth and likewise the germs of the permanent teeth except the second and third molars. Three to five years are required for the completion of the roots after which they remain complete for a similar length of time. During this period the permanent teeth have been developing in their crypts after which they begin their occlusal movement. The first observation of importance is the appearance of osteoclasts on the roof of the crypt. Penetrating the crypt roof the permanent tooth approaches the lingual surface of the temporary tooth if it is an incisor or cuspid, and immediately between the roots if it be a posterior tooth. Incisors of dogs have a tendency to point directly to the apices of their temporary predecessors (see Fig. 235) while those of sheep simulate those in the human mouth, approaching the lingual surface. The difference presents interesting features for our notice. The removal of the tissue in the path of the advancing tooth is more rapid than the advance of that tooth with the result that the way cleared is filled with young fibrous connective tissue rich in budding capillaries (see Fig. 234, *d*). In the wake of the tooth, bone spicules are developed supportive to the crypt for it will be observed that at first the crypt moves with the structures it contains, thus affording an important mechanical factor in the development of the jaw.

Coincident with the approach of the permanent tooth germ to the root of the temporary tooth osteoclasts appear on the approached surface of the deciduous root. Also capillary loops develop extending toward them in a manner strikingly similar to that seen when calcification is in progress for these activities always call for a copious blood supply (see Figs. 235, *a*, and 237, *b*). The work of the osteoclast is never long confined to the area mentioned. The stimulus afforded

[1] The Establishment of the Circulation of the Cerebrospinal Fluid, Anat. Record, x, 256–158.

[2] Histopathological Changes in a Case of Amyotrophic Lateral Sclerosis, Med. Rec., February 10, 1917.

[3] Histologische und Histopathologische, Arbeiten von Nissl und Antzheimer, 1912.

to the peridental membrane soon permeates it with the result that osteoclasts appear on any surface, anywhere from the apex to the gingival line (see Fig. 235, *b*). Occasionally the spaces excavated are filled with cementum and a new attachment made, but that is far from consistent. Whereas the approaching permanent tooth apparently is the original stimulus to the destructive process the

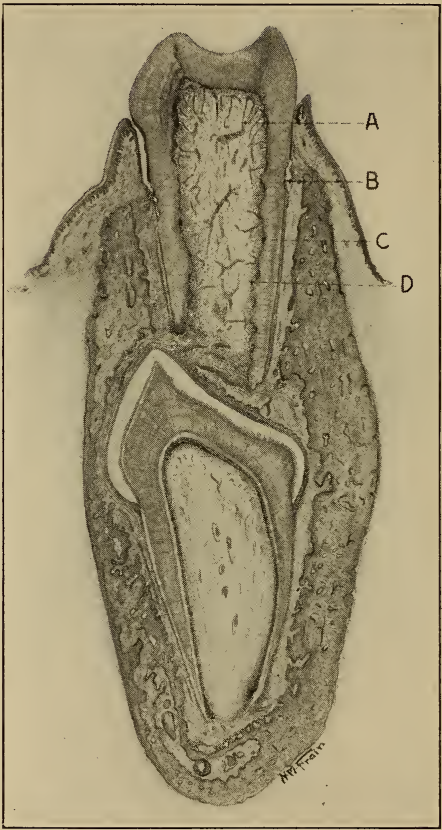


Fig. 235.—Section of a dog's tooth, showing internal and external absorption. *A*, capillary loops to absorption areas; *B*, absorption area at the cervix of the tooth; *C*, foveolæ on pulpal surface of root; *D*, cellular layer surrounding the pulp.

ragged edges made by the absorption doubtless afford a secondary stimulus and the area where no new cementum is deposited has the effect of a foreign body, all of which tends to speed the absorption. The beginning of absorption and its continuance are in no way affected seemingly by the fact of pulp extirpation provided that the root is aseptic. Instances are plentiful showing perfect removal of the root leaving a cone of filling material in the tissue. A curious and interesting phenomenon may be observed in the museum of the Northwestern University Dental School. A series of teeth are shown on which is a small tube of dentin around the canal which was preserved around the pulp apparently in resistance to the absorbing agents. Normally the process continues until the root is wholly gone and it is often seen that the dentin of the crown has been entirely removed and sometimes the enamel has been reduced to the thinness of tissue paper.

Apparently no changes appear in the pulp due to the external absorption of the tooth root. The writer has never observed any effects upon the pulp due to changes in progress on the exterior of the tooth root; it shows no reaction until it is invaded. The embryonic character of the tissue naturally undergoes immediate alteration when its environment is changed. When the absorption has been greatest at the apex and a large area of pulp is uncovered the effect upon the pulp is widespread. Around the periphery new connective-tissue elements appear extending farther and farther occlusally around the pulpal walls until all the odontoblasts are lost and in their places is a dense cellular zone containing a preponderance of undifferentiated connective-tissue cells (see Fig. 235, *d*). Upon the outer surface of this cellular layer osteoclasts appear and internal absorption accompanies that which progresses on the exterior root surface (see Fig. 235, *c*). Some fibroblasts are seen and an abundance of capillary loops extends radially from much enlarged central vessels to the absorbing cells (see Fig. 235, *a*). Hence, the pulp has been metamorphosed into a scrap of typical granulation tissue. Should the opening into the pulp chamber elsewhere be small, similar changes occur in the immediate vicinity of the penetration. The more distant parts of the pulp, be they coronal or apical, remain practically normal until the point of invasion has become large enough to affect the entire structure or numerous penetrations are made.

During this process it will be noted that although pressure may be assigned as the stimulus to absorption that stimulus is never retroactive. No osteoclasts ever appear inside the follicle of the erupting tooth which causes the pressure. Also, should acid be produced by the cells for the purpose of decalcification it never affects the permanent tooth. The follicle seems to be a sufficient protection against such emergencies, and it persists until the tooth reaches the surface of the gum. It may likewise be inferred that no tissue can be referred to as an absorbent organ, as we have seen that absorption extends over the surfaces of the tooth externally as well as internally. Absorption of the roots of the teeth of different species is observed to follow a routine which is a modification of the one described, the general principle being the same.

Under the head of physiological absorptions must be considered the removal of implanted teeth. It has been long observed that implanted teeth are of brief service in the mouth and that when they are removed their root surfaces are pitted and rough or entirely absorbed (Figs 236 and 241). Although to my knowledge no sections of implanted teeth have ever been made with the surrounding supporting tissue the explanation of both their short period of serviceability and the pitted surfaces seems obvious. The

Fig. 236.—A bicuspid tooth which was implanted and remained in the alveolus about three years. (Fig. 119 in Special Dental Pathology, Black.)

inserted tooth is placed in an artificially created alveolus which nature attempts to close. To do so agents for the removal of the foreign body attack its surface and bone formation follows in the wake filling the indentations with its extensions. The attack in this case is uniform upon the surface of the root unless there are pathological interferences. A great surgeon is accredited with saying "The more perfect the operation of placing the tooth the more rapid is the removal" (Gilmer). It is the projections of bone into the foveolæ made by the osteoclasts that give the tooth its firmness. An x-ray of such a tooth shows no clear periphery as is the case with teeth normally attached but rather a confused picture due to the bridges of bone extending into the tooth root.

Under pathological absorptions, first come those found in the walls of the pulp chamber. Causch[1] mentions excavations in the

[1] Tr. of World's Columbian Dental Congress, p. 114.

pulpal walls as does Salter and describes the same as filled with bone.[1] It will be remembered that the older histologists and some modern ones call every tooth tissue bone, if it is not definite in structure. It was his findings in these studies that led him to consider odontoblasts as contributing to the formation of osteoclasts. Absorptions in the dentin surrounding the pulp chamber and canals

Fig. 237.—Section of a dog's tooth, showing blood supply to enamel forming cells. *A*, ameloblasts; *B*, vessels.

are very common and not infrequently contain filling of calcified material varying in structure from an irregularly arranged dentin to a clear structureless deposit (Figs. 239 and 240). No one has observed osteoclasts in the pulp-chamber of a tooth that has not been invaded. But there is no reason for doubting that they may appear there and other phagocytes as before mentioned may

[1] Black: Special Dental Pathology, p. 265.

accomplish the results observed. The observations are there and frequently enough penetrate to the outside. Hess in a series of studies on multiple foramina reports that canals are often formed from within out to compensate for canals closed by secondary deposits of cementum.[1] Such fillings of canals are common observations in ground sections (see Fig. 131).

Absorptions on permanent teeth are very common. They are associated with impactions and are noticed on the apices of roots about which are abscesses as well as around the cervices of teeth. Sometimes the abscess is given as the possible cause of the tissue

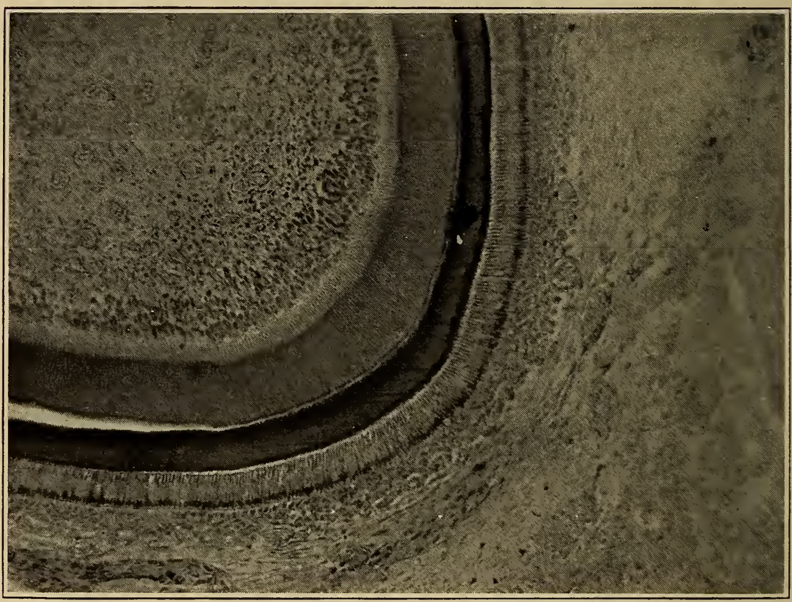


Fig. 238.—Photograph of section from which Fig. 237 was made.

destruction. It does not seem probable, however, that the acid content of pus destroys the tooth root and it is very certain that no cell, osteoblast or osteoclast, ever approaches a root which has been bathed in pus as it does under physiological conditions. Believing that the tissue destruction is accomplished by cells and not by acids, the excavations must be made before the pus reaches the cementum, the cells being stimulated to activity possibly by the

[1] Hess: The Development and Structure of the Tooth Apex and Features Pertaining Thereto, Zahnheilkunde, 1917, xxxvi.

inflammation. Explaining the other absorptions mentioned Inglis suggests that such causes as protruding root canal fillings, broaches, pericemental deposits and salivary calculus may instigate cellular activity.[1] It is true that the absorptions occur most commonly

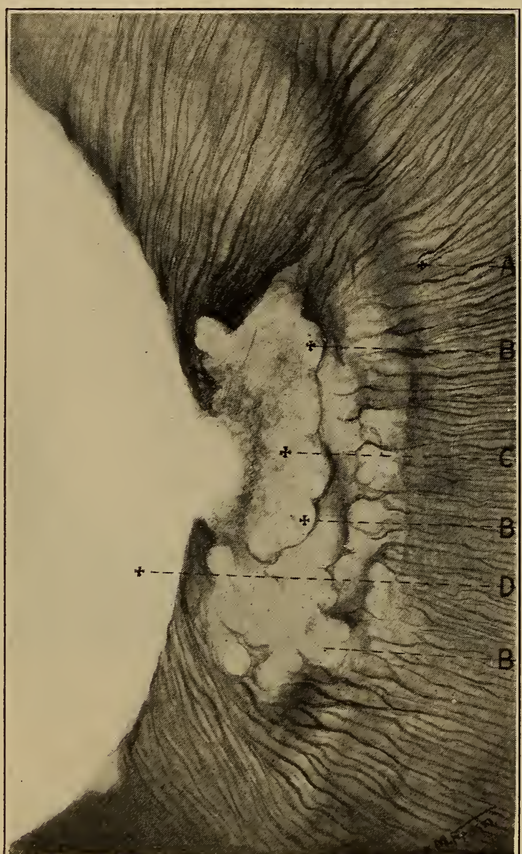


Fig. 239.—Section of human tooth, showing an internal absorption area which has been almost completely filled with structureless calcified material. *A*, primary dentin; *B*, foveolæ; *C*, structureless calcified material; *D*, root canal.

on the cervical and apical areas where inflammations are the commonest (see Fig. 241).

More interesting than the foregoing is the entire removal of the roots of permanent teeth, sometimes limited to a single tooth, or, as

[1] Burchard and Inglis: Dental Pathology and Therapeutics, 1912, p. 622.

has been reported by Black,[1] of all the teeth, in exactly the same way as deciduous teeth are removed. Where such removals have taken

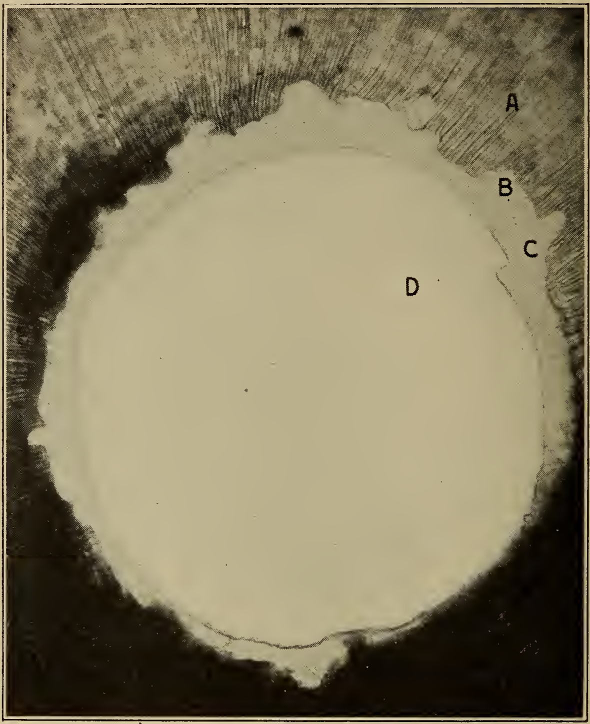


Fig. 240.—Showing absorption of pulpal walls and newly deposited, structureless, calcified tissue. *A*, dentin; *B*, foveolæ; *C*, new calcified tissue; *D*, canal.

Fig. 241.—Showing absorption of a tooth implanted by Dr. Thomas L. Gilmer. When this radiograph was taken the tooth had been in the alveolus nearly three years, (Fig. 118, Special Dental Pathology, Black).

[1] Special Dental Pathology, p. 33.

place the patient has never reported any accompanying symptoms. The process has been painless. No etiology of such conditions is forthcoming. That question being laid aside there is no reason for doubting that the agents employed are the same as for deciduous teeth. Could sections be made of these teeth *in situ* doubtless we should find upon their surfaces osteoclasts accomplishing the purpose.

To summarize it seems strongly evident that osteoclasts or their endothelial predecessors are the active agents of absorption, although the method by which they accomplish it is unknown. Such is their distribution on both the internal and external surfaces of the tooth that neither the pulp nor the peridental membrane can logically be termed an absorbent organ. These cells destroy soft and hard tissues alike, outlines of them being visible in the dense peridental membrane surrounding the wasting tooth (see Fig. 234, *c*). Especial emphasis is laid upon the connective-tissue changes that take place, changes in both the hard and soft tissues as well as changes in the blood supply. What seems so evident in the study of the removal of the temporary teeth and in bone seems a well justified explanation of the removal of the structures mentioned where exact data is so difficult to acquire.

CHAPTER XXIII.

THE MOUTH CAVITY.

Mucous Membrane.—The mucous membrane lining the mouth cavity is composed of a layer of stratified squamous epithelium supported upon a tunica propria, which is usually described as composed of two parts—the papillary layer and the reticular layer. The epithelium and the tunica propria make up the mucous membrane proper, which is supported upon a submucous layer composed of a coarse network of white and elastic fibers, containing the larger bloodvessels.

The Epithelium.—The stratified squamous epithelium is provided with a horny or corneous layer only in the portions covering the alveolar process and the hard palate, or, in other words, where the submucosa is firmly attached to the periosteum (Fig. 242). In these positions the horny layer consists of dead cells which have lost their nuclei and whose cytoplasm has been converted into keratin or horny material.

These scale-like cell remains are closely packed into a protective layer. There is no distinct stratum lucidum separating the dead from the living cells, as there is in the skin. In the deeper portions the cells possess oval or rounded nuclei and become larger and more polyhedral as the basement membrane is approached. The cells of the deepest layer next to the basement membrane are tall and approach the columnar form, but are never much greater in height than width. The deep layer is often called stratum Malpighii. The epithelium lining the gingival space and that covering unattached portions is without the horny layer, and the cells are larger and more loosely placed. The polyhedral cells in the middle portion of the layer show distinct intercellular spaces across which the cytoplasm extends in intercellular bridges.

Isolated cells from this region show the broken bridges projecting from their surface, and for this reason have been called "pickle or prickle cells." In these positions the thickness of the epithelial layer is usually greater than in the attached portions of the membrane (Fig. 243).

Tunica Propria.—The connective-tissue layer of the mucous membrane interlocks with the epithelial layer by means of the tunica papillaris, which is composed of very delicate white and elastic connective-tissue fibers. They are usually about half as tall as the thickness of the epithelium, and about one-third as wide as they are tall. The height and character of the papillæ varies greatly, however, in different position. In the red border of the lip and in the epithelium lining the gingival space they are very tall and narrow, and approach very close to the surface of the epithelium. Over the gums and the palate they are much shorter

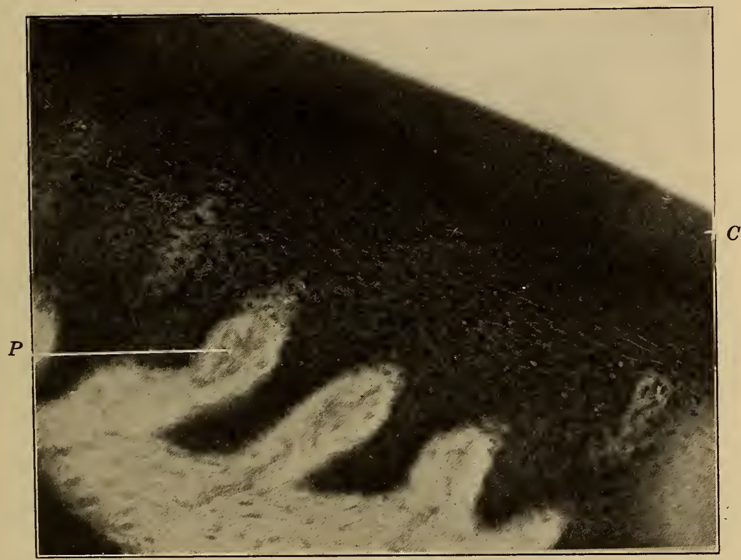


FIG. 242.—Stratified squamous epithelium covering the alveolar process: *C*, corneous layer; *P*, papilla of connective tissue. (About 400 ×)

and wider and do not extend more than half-way through the epithelium. These papillæ contain loops of capillary bloodvessels and in some special nerve endings are found.

Reticular Layer.—The reticular layer joins the papillary layer without any line of demarcation, and is composed of the same kind of tissue, the fibers being arranged in a delicate network. Everywhere in the tunica propria are found ducts from mucous gland which lie in the deeper layers.

Submucosa.—The submucosa is composed of firm connective tissue in which the white fibers are in large, strong bundles, and elastic fibers are scarce. It contains two plexuses of bloodvessels, both more or less parallel with the surface. The outer is composed of small vessels forming a small-meshed network, the deeper of large vessels more widely separated. Lymphatic vessels everywhere follow the course of the bloodvessels.

Glands of the Submucosa.—The submucosa contains a great many small tubular glands. These are distributed widely over the tongue and membrane of the cheek and lip (Fig. 244). They are branched tubular glands, sometimes simple and sometimes compound. The body of the gland is always in the submucosa, though it may extend into the underlying muscle. Some are serous and others

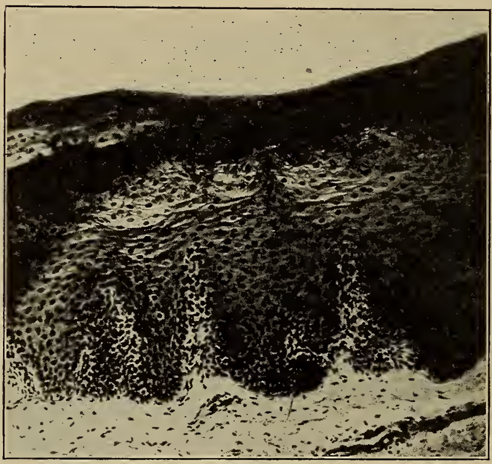


Fig. 243.—Stratified squamous epithelium from unattached mucous membrane of the mouth. The corneous layer is absent. (About 200 ×)

mucous, while many of the larger ones contain cells of both types. The secretion of these glands is probably much more important than has been supposed.

Nerve Endings in the Mucosa.—Sensory nerve endings of two kinds are found in the mucous membrane. Krause's end bulbs are found in many of the papillæ, and other nerves terminate in free endings lying between the epithelial cells.

The Tongue.—The tongue is composed of a mass of voluntary muscle fibers arranged in complicated interlacing bundles, covered by the mucous membrane. The most striking characteristics of the mucous membrane of the tongue (Fig. 245) are: (1) The thinness of the submucosa, which holds it closely to the mass of muscle and allows very little movement of it; (2) the submucosa in the dorsal surface contains no glands, though there are glands among the muscle fibers whose ducts pass through the submucosa; (3) the presence of the epithelial papillæ upon its dorsal surface.

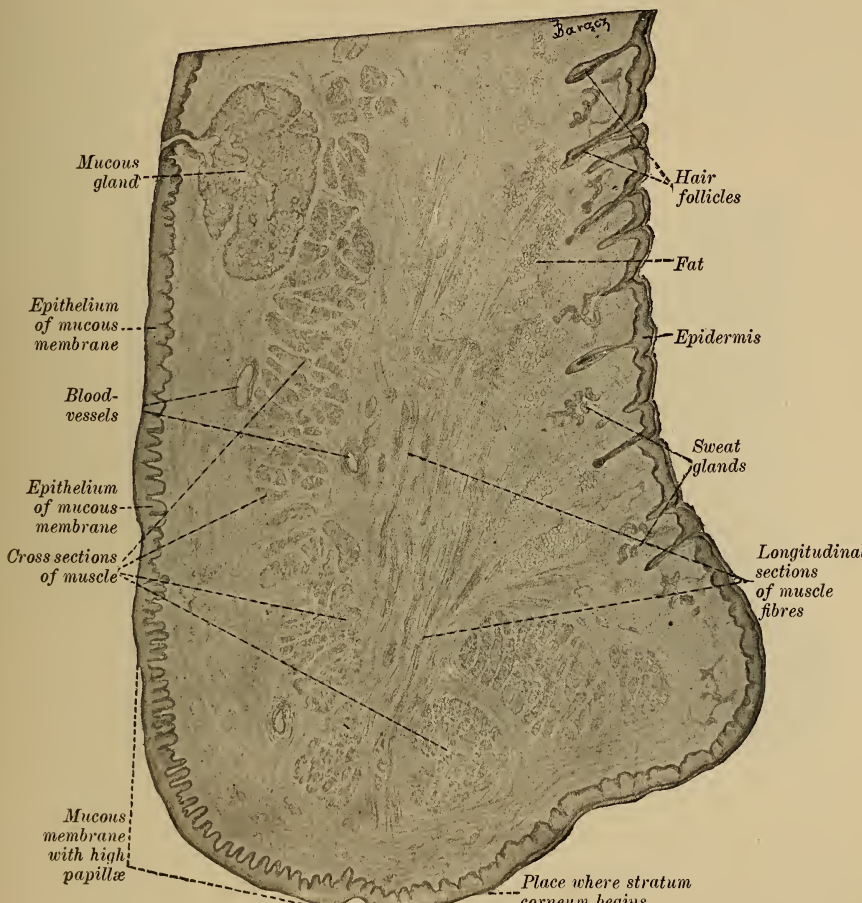


Fig. 244.—Section through the upper lip of a two-and-a-half-year-old child. (14 ×) (Szymonowicz.)

The tongue is imperfectly divided vertically on the median line by a band of connective tissue forming the median raphe or septum, which causes the depression at the central line of the dorsal surface.

The Muscles.—The muscles of the tongue include two groups—the extrinsic and the intrinsic. The extrinsic muscles comprise the genioglossus, the hyoglossus, the styloglossus, and the palatoglossus. These are all paired and extend from the skull or the hyoid bone into the tongue. The intrinsic muscles comprise the principal muscles of the tongue, the lingualis. A transverse section through the body of the tongue in the central portion shows a complicated network of muscle fibers running in three directions—longitudinally, transversely, and vertically. The longitudinal fibers are arranged around the outer portion, forming a cortical layer about 5 mm. thick. These constitute the chief bulk of the lingualis, supple-

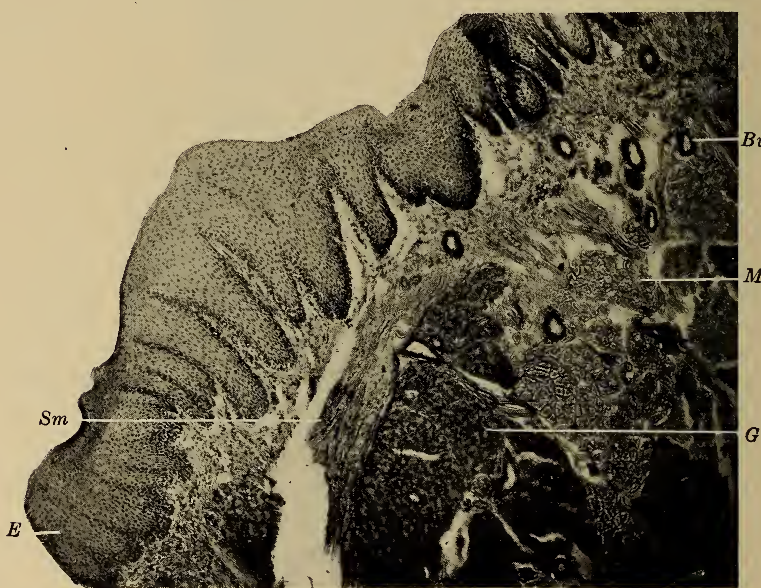


Fig. 245.—A section from the side of the tongue: *E*, epithelium; *Sm*, submucosa; *Bv*, bloodvessels; *M*, muscle fibers; *G*, mucous glands.

mented by fibers from the styloglossus. The vertical fibers are mostly deeply placed in the central portion on either side of the raphe. They are chiefly derived from the genioglossus and radiate toward the dorsal surface. The transverse fibers are entirely from the lingualis except for a few from the palatoglossus. They arise from the septum and interlace with the longitudinal and vertical fibers. They break up into strands running between the longitudinal fibers of the cortical portion, and spread out to a submucous insertion.

The complicated movements of the tongue are accomplished by the contractions of these sets of muscles. When the longitudinal fibers are relaxed and the transverse fibers contracted the tongue is rolled and extended. When the transverse fibers are relaxed and the vertical fibers contracted the tongue is flattened. The division of the tongue on the median line by the septum allows each half to work independently, so that when the longitudinal fibers are contracted on one side and relaxed on the other the tip of the tongue is moved sidewise.

Fig. 246.—Mucous membrane from the dorsal surface of the tongue of a kitten, showing filiform and fungiform papillæ.

The Papillæ.—The roughness of the dorsal surface of the tongue is caused by projections of the epithelium resting upon the tunica propria, forming the papillæ of the tongue. These projections are not to be confused with the connective-tissue papillæ in the tunica propria of the mucous membrane. They are of three kinds—the filiform and fungiform papillæ, which are found over the entire dorsal surface, and the circumvallate papillæ, which are limited in number and confined to the posterior portion. The filiform are much the more numerous, especially near the tip of the tongue. They are from 0.5 to 2.5 mm. in height, and often end in brush-like strands of epithelial cells.

The fungiform papillæ form the red points on the surface of the tongue, especially near the edges, because of the thinness of their

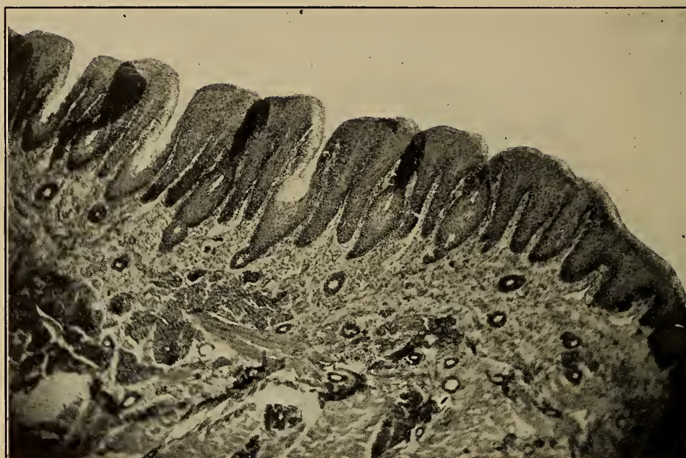


Fig. 247.—Mucous membrane from the tongue of a rabbit, showing circumvallate papillæ, with taste-buds on their sides.

epithelium. They are low and rounded in form, from 0.5 to 1.5 mm. in height, and are named from their mushroom-like appearance. Fig. 246, a section from the tongue of a kitten, shows the form of both of these papillæ. The circumvallate papillæ usually number

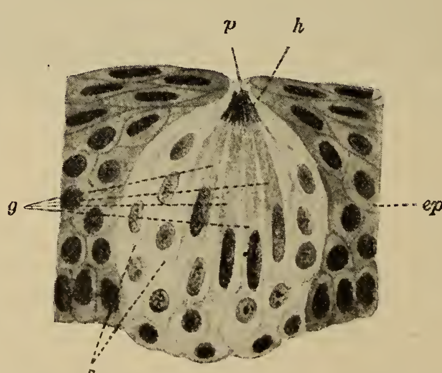


Fig. 248.—A section of a taste-bud: *p*, pore; *g*, gustatory cells; *ep*, epithelial cells; *s*, sustentacular cells; *h*, bristles of the gustatory cells. (Schaefer.)

nine or ten, and are arranged in a V-shaped form near the base of the tongue, with the apex extending backward. They are from 1 to 1.5 mm. in height and from 2 to 3.5 mm. in width. They are surrounded by a depression, so that the upper surface of the papillæ is not much above the general level of the membrane.

The Taste-buds.—These are found chiefly on the sides of the circumvallate papillæ (Fig. 247), though they are occasionally found in the epithelium of the fungiform papillæ and the soft palate, and on the posterior surface of the epiglottis. They are always entirely embedded in the epithelium and extend through its entire thickness. The structures are ovoid in form, with the rounded end toward the connective tissue and the pointed end at the sur-

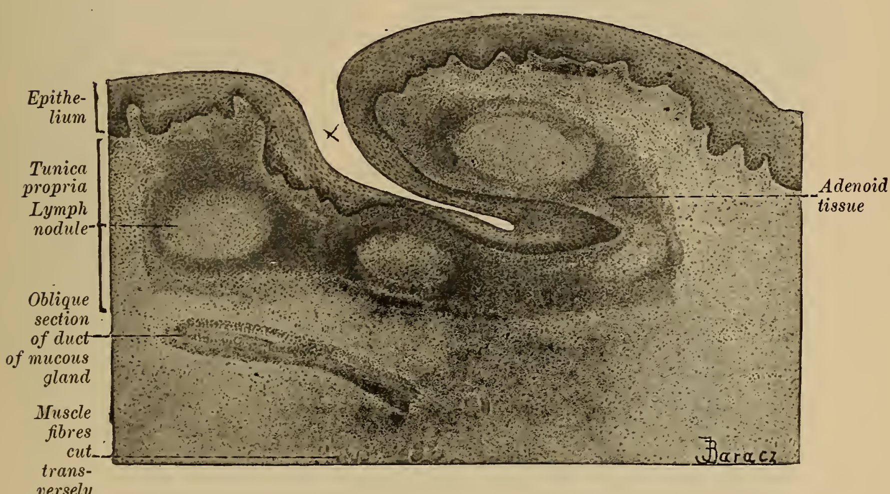


FIG. 249.—Section through a lingual follicle in man: *x*, crypt. (50 ×) (Szymonowicz.)

face, where a small opening, the taste-pore, communicates with the mouth cavity (Fig. 248). Most of the cells are elongated and spindle-shaped, and arranged like the leaves of an onion. Four varieties may be recognized. The outer sustentacular cells form the outer layer and are in contact with the epithelial cells. They are elongated, with an oval nucleus near the center. The inner sustentacular are rod-shaped cells, more slender in form, with a nucleus at the base. The neuro-epithelial cells are elongated, spindle-shaped cells at the center of the taste-bud. The nucleus is at the base of the cell, and from the opposite end a stiff bristle-like process extends through the taste-pore.

The basal cells are irregular in form with large oval nuclei; they communicate with each other and the sustentacular cells by cytoplasmic bridges. They form the base of the taste-bud. The func-

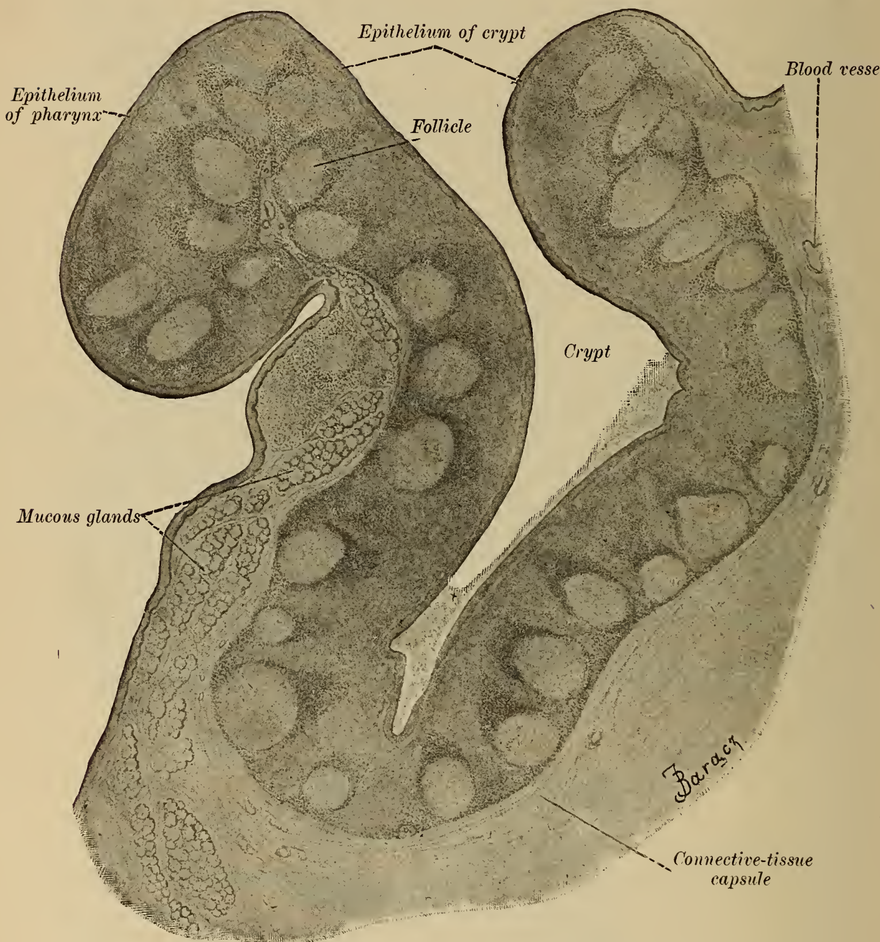


Fig. 250.—Section through a dog's tonsil. At x, x there are seen leukocytes which have wandered out from the follicles. (15 ×) (Szymonowicz.)

tion of the taste-buds is probably related to the function of deglutition rather than the sensation of taste.

The Tonsil.—In the posterior part of the tongue and the wall of the pharynx is found adenoid tissue in the form of solitary follicles lying in the tunica propria and invading the epithelium. This adenoid tissue forms an organ which Waldeyer has called the lymphatic pharyngeal ring. This tissue is divided into three main masses—that lying in the base of the tongue forming the lingual tonsil, that associated with the palate and lying between the pillars of the pharynx and forming the palatine tonsil, and that situated in the pharynx or pharyngeal tonsil.

The Lingual Tonsils—These are situated in the base of the tongue between the circumvallate papillæ and the epiglottis. They are rounded masses of adenoid tissue composed of solitary follicles lying mostly in the tunica propria, and causing projections of the surface that are easily seen. In the center of each mass is a deep depression forming a blind pouch, known as the crypt (Fig. 249). This is lined with stratified squamous epithelium like that of the adjoining mucous membrane except that at various places the lymphocytes have pushed their way through the epithelial cells, and escape on the surface.

The Palatine Tonsils.—These lie at the base of the tongue between the anterior and the posterior pillars of the pharynx. They are much larger than the lingual tonsils and are composed of from ten to twenty follicles and a number of crypts. The epithelium covering them is pierced in many places by encroachments of the adenoid tissue. The crypts always contain many lymphocytes (Fig. 250). These are what are ordinarily called the tonsils, the infection of which produces tonsillitis.

The Pharyngeal Tonsils.—These lie on the posterior wall of the nasal pharynx above the level of the palate. Their structure is similar to that of the palatine tonsil. The crypts are five to six in number and are often clothed with ciliated epithelium. Into them open the ducts of mixed glands which form a distinct layer under the follicle. Here also there is a migration of lymphocytes through the epithelium. It is the hypertrophy of these which form the adenoids so often found in children.

CHAPTER XXIV.

BIOLOGICAL CONSIDERATIONS FUNDAMENTAL TO EMBRYOLOGY.

History.—Before beginning the study of embryology some topics in general histology must be reviewed, and some general biologic ideas considered. No real conception of the complicated process of individual development can be obtained without laying a foundation in the study of the cell as the units of life and the mechanism through which the phenomena of life are manifested.

In embryology it is found that the individual in his physical development passes through stages which correspond to the development of the race or species to which he belongs, and a like comparison might be drawn in mental development and the acquirement of knowledge. This is specially true of the subject of embryology.

Apparently the first ideas to occupy the speculative thought of man when he became conscious of himself as an independent being were the questions of his origin and the relation to his environment and destiny. These have become the basis for the development of all religious thought.

Up to the beginning of the nineteenth century all considerations of these subjects were purely speculative. The old question of "What is life?" received endless discussion. In the nineteenth century this question has been dropped into the background, and the question, "What is the mechanism of life?" has been substituted for it. The consideration of the latter question has resulted not only in the marvellous advancement of medical knowledge and surgical skill, but in the great development of deeper fundamental thoughts. It must not be forgotten, however, that the development of knowledge resulting from the consideration of the latter question has not and does not promise to answer the old question, "What is life?" any more than the laws of electricity and their application to its use answer the question, "What is electricity?"

The discovery of the cell hypothesis and the propounding of the theory of organic evolution have been the greatest factors in the unification of knowledge and the stimulation of thought in these fields. It is interesting to notice that these two theories, closely related as they have become, had entirely independent origins and were long followed out without any immediate connection. The theory of evolution was based upon consideration of the forms of living things, their distribution and adaptation to environment.

The Cell Theory.—The cell theory had its origin in the study of minute forms. Its beginnings were made possible by the development of the compound microscope, which revealed their structure and showed them to be small bodies made up of apparently a structureless, granular material which was called protoplasm, or the ultimate substance of life. This material, as its name indicates was originally supposed to be simple in structure and composition and to be the life substance. Huxley's characterization of it as the "physical basis of life" was the beginning of the study which has revealed it to be very far from a simple substance, but rather extremely complex both in structural arrangement and chemical composition. In more recent biology, therefore, the word protoplasm is being dropped and the word cytoplasm or cell substance substituted for it.

The early history of the cell theory was obstructed in its development by the remains of the old Greek idea that living things could originate from non-living matter, that the swamp breeds disease, and the decomposing body of an animal, maggots. It required fifty years of work on the cell theory for Virchow, in 1850, to propound his thesis that all living cells are derived from a preëxisting cell, and so establish the continuity of life, which has flowed on from the beginning in an uninterrupted stream, each individual being only a period.

When Schwann and Schleiden showed that the bodies of both plants and animals, instead of being made up of homogeneous tissue, were composed of millions of structural elements which they called cells, the consideration of both plants and animals were for the first time put upon a common basis. Naturally enough the first thing to attract attention was the study of the form and arrangementof these structural elements in the tissuesof animals andplants.

In following out this study it became more and more evident that, while infinitely varied in the detail of their form and structure, all cells had a common plan of organization and possessed structural characteristics common to all, at least in some stages of their history.

Relation of the Nucleus to the Protoplasm.—The first point to be discovered in the internal organization of the cell was the nucleus, the meaning of which and its relation to the cytoplasm at once attracted attention. As the result of a vast amount of work, it was gradually established that the nucleus "exerts a controlling and directing influence over the activity of the cytoplasm;" that a cell deprived of its nucleus would continue to live for a longer or shorter time, but that it would not grow and would not reproduce another cell; that the phenomena of life manifested by destructive metabolism would continue until the identity of the cytoplasm was destroyed, but there would be no constructive metabolism. The work of the cytoplasm is therefore dependent upon the character of the nuclear material.

Cell Division.—As first observed, cell division was supposed to be an irregular cutting of the cytoplasm and the nucleus in two, forming two individual cells. The cytoplasm by its constructive changes does not continue to increase indefinitely, but as soon as a certain size is reached it divides, a portion of the nucleus going to each of the parts, which immediately begin to increase in size. It was soon found that cell division was not always so simple, and that in some cases changes in the nucleus preceded the division of the cytoplasm. Two forms of cell division are therefore described, the simple or direct, and indirect or karyokinetic cell division. The simple is now known to be comparatively rare.

Indirect Cell Division.—Indirect cell division must be considered as a means by which the chromatic material of the nucleus is equally and systematically distributed to the resulting cells. The nucleus, in cell division, contains a beautiful structural mechanism, by which the material which is to control the development of the resulting cells and their activity is definitely distributed to them. In this process there is no irregularity in the kind or amount of material given to the two cells.

In this process the chromatin of the original nucleus is divided into a definite number of pieces which are split in two, and half of each sent to each new nucleus, where they form its chromatin network.

The Vehicle of Transmission.—It was discovered that the number of chromosomes was constant in every cell division for all the cells of all the tissues of the given species, and was, therefore, a characteristic of the species; and that in all the cells of the body it was always an even number, and that in the germ cells of the species the number of chromosomes was exactly half that in the cells of the body. This led to the immediate recognition of the chromatic material as the vehicle of transmission. When in the study of fertilization it was found that fertilization consists in the union of two cells, each contributing both cytoplasm and nucleus, and that the amount of chromatic material was equal from each, and exactly half that found in the cells of the parent body, the equality of the sexes in transmission was firmly established upon a cytologic basis. It is interesting to note that this equality had previously been claimed by the disciples of the evolutionary theory, and it was in this field that the evolutionary theory and the cell theory first met on common grounds (about 1875).

All the advancement in modern thought concerning heredity and transmission has resulted from these discoveries. The practical results are perhaps still more important in the artificial breeding of plants and animals, adapting them to their environment. The work of such men as Burbank may be said to be the application of the knowledge of the mechanism of cell division and inheritance to horticulture and agriculture.

Chemical Ideas.—At the present time the structural mechanism of life, while inviting many fields for research, may be said to have nearly reached the limit of possibilities of observation, and at the present time the chemical phase is attracting the greatest attention. Such questions as, "How does the nucleus influence the activity of the cytoplasm?" are being eagerly investigated. Cytoplasm while enormously complex in chemical composition, must, nevertheless, always be thought of as performing its vital functions by chemical activity. It is constantly building simpler molecules into its own, and so increasing in amount. For this its surface must be bathed in materials with which it can react. It is evident that if the mass increased indefinitely the volume would increase much more rapidly than the surface, and this puts a limit upon the growth.

The constructive metabolism of the cytoplasm is dependent upon the presence of the chromatin in the nucleus. In the process of metabolism, therefore, there must be interaction between the chemical substances of the chromatin, cytoplasm, and food material. The development of physiologic chemistry is rapidly affecting the ideas of the cause and treatment of disease, and especially the production of immunity and susceptibility.

If the dental profession is to keep pace with the development in these fields and apply the results of investigation to the treatment of diseases of the mouth, the study of the fundamental sciences must be more thorough.

CHAPTER XXV.

EARLY STAGES OF EMBRYOLOGY.

SINCE fertilization consists essentially in the union of the chromatin from two cells, and as the result of the union restores the normal amount of chromatin for the cells of that species, it is evident that

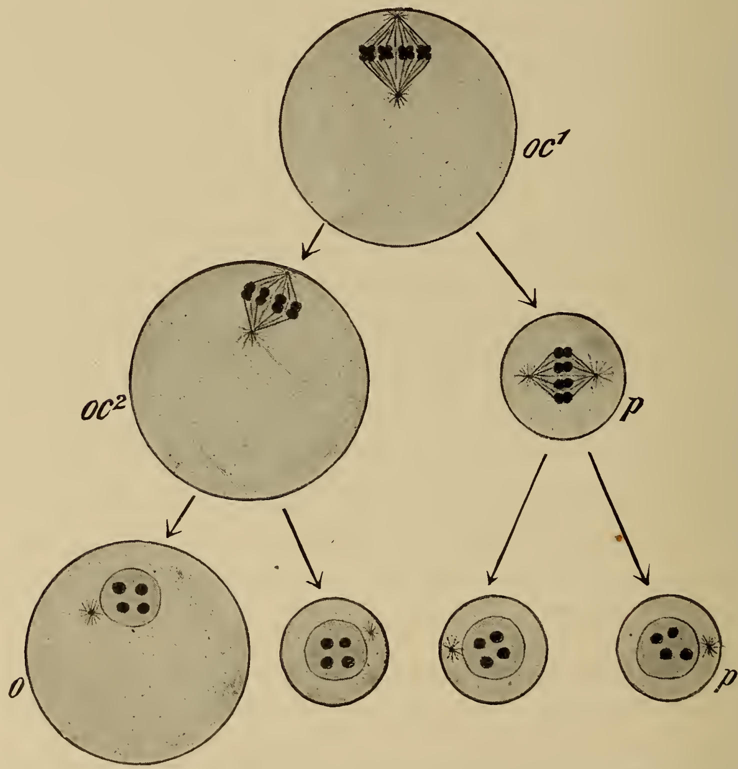


FIG. 251.—Diagram illustrating the reduction of the chromosomes during the maturation of the ovum: *o*, ovum; *oc*¹, oöcyte of the first generation; *oc*², oöcyte of the second generation; *p*, *p*, polar bodies. (McMurrich.)

in some way the germ cells must be prepared for fertilization by the loss of half their chromatin. This process was first observed in the case of the ovum.

Maturation.—In observing fertilization of eggs of the starfish and various threadworms, it was noticed that before fertilization occurred the nucleus of the ovum divided with karyokinetic figures, forming three small bodies known as polar bodies. This process is diagrammed in Fig. 251. In reality, the ovum first divides, forming one polar body; the polar body and the ovum both then divide again, so that the result of the two series of division is the

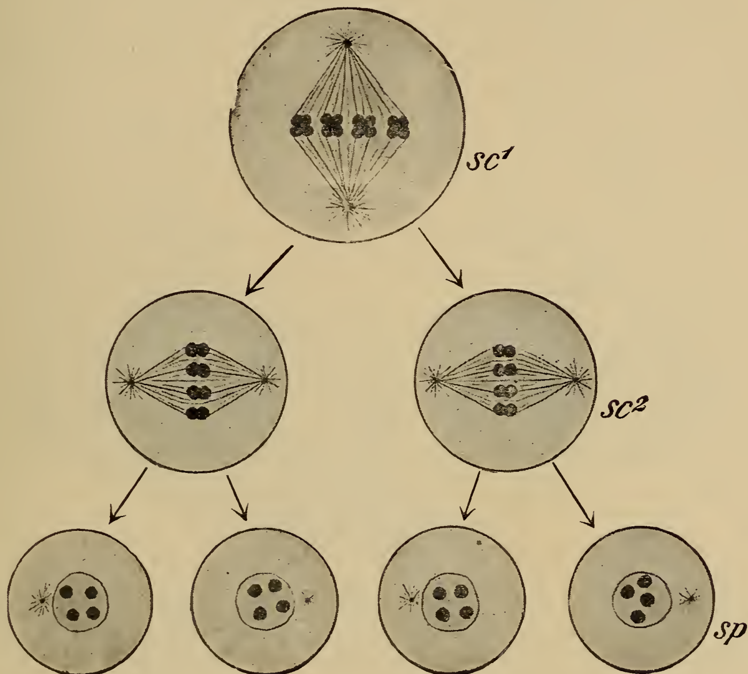


Fig. 252.—Diagram illustrating the reduction of the chromosomes during spermatogenesis: sc^1, spermatocyte of the first order; sc^2, spermatocyte of the second order; *sp*, spermatid. (McMurrich.)

formation of four cells, one of which is functional, three disappearing. This process is practically universal in the formation of ova of both plants and animals. The cells in the ovary which form the ova are called oögonia. The cells formed from these are the primary oöcyte. The division of this cell produces two secondary oöcytes, of which one disappears later. The division of the secondary oöcyte results in the ovum and three polar bodies. The number of chromosomes in the primary oöcyte is half the number characteristic of the somatic cells, but they are made up of four pieces. In the secondary oöcytes they are the same number but double. In the ovum and polar bodies they are the same in number and single.

Spermatogenesis.—Exactly the same series of changes occur in the formation of the spermatozoa. They are illustrated in Fig. 252. On the outer wall of the seminiferous tubules are two forms of cells, the spermatogonia and the cells of Sertoli (Fig. 253). The cell of Sertoli increases in size and spreads out against the basement membrane, pushing the spermatogonia away from it. They now divide, forming two cells, one of which returns to the basement membrane and remains as the spermatogonia, the other becomes a primary spermatocyte. The primary spermatocytes divide, forming a secondary; the secondary divide, forming spermatids, which

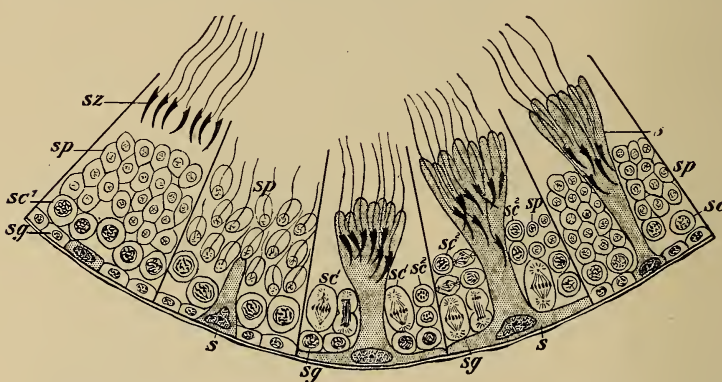


FIG. 253.—Diagram showing stages of spermatogenesis as seen in different sections of a seminiferous tubule of a rat: *s*, sertoli cell; *sc*^{1}, spermatocyte of the first order; *sc*^{2}, spermatocyte of the second order; *sg*, spermatogone; *sp*, spermatid; *sz*, spermatozoön. (Von Lenhossek's diagram from McMurrich.)

develop directly into spermatozoa. By comparing the diagrams they will be seen to correspond exactly with the formation of the ova, except that all of the cells are small and motile. The nuclear changes also correspond to those of the ova, the primary spermatocyte having half the number of tetrad chromosomes, the secondary half the number of diad, and the spermatids half the number of monad chromosomes.

Fertilization.—Fertilization is essentially the same in the sexual reproduction of all plants and animals. It may be easily observed in the transparent cells of such animals as the starfish and the threadworm. The spermatozoön enters the cytoplasm of the ova,

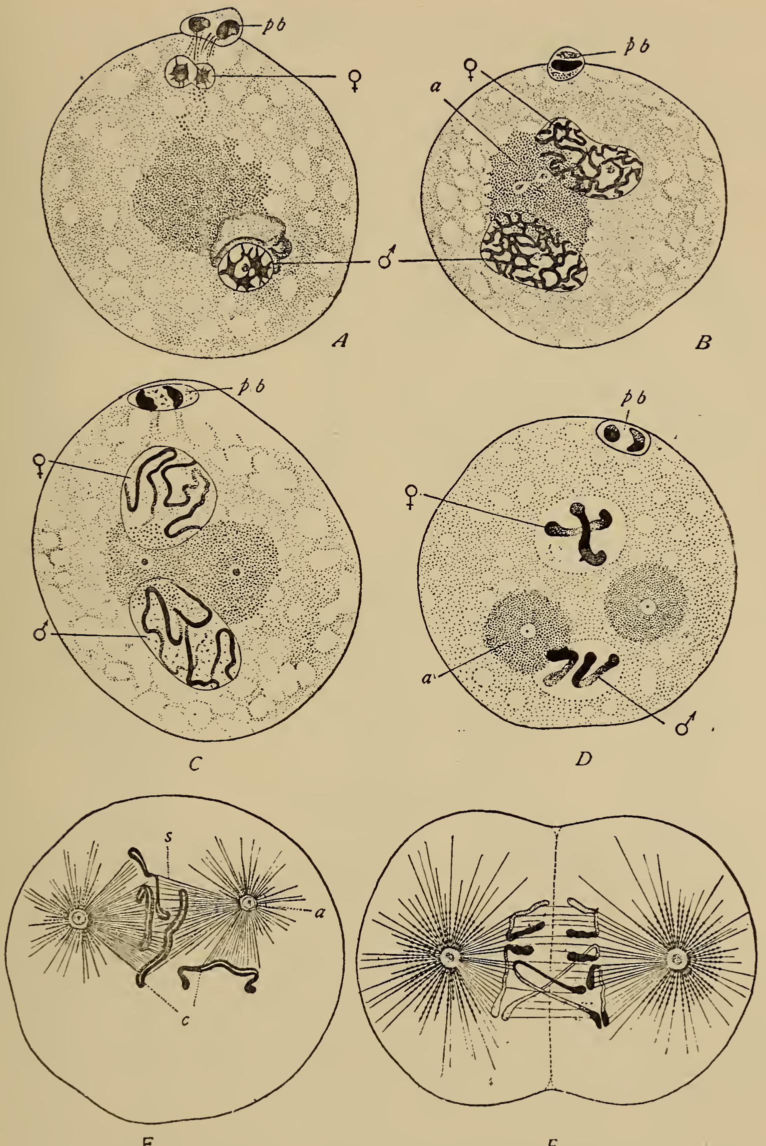


FIG. 254.—Fertilization of the egg of *Ascaris megalocephala*, var. *bivalens*. (Boveri.) *A*, the spermatozoön has entered the egg; its nucleus is shown at ♂; beside it lies the granular mass of "archoplasm" (attraction sphere); above are the closing phases in the formation of the second polar body (two chromosomes in each nucleus). *B*, germ nuclei (♀, ♂) in the reticular stage; the attraction sphere (*a*) contains the dividing centrosome. *C*, chromosomes forming in the germ nuclei; the centrosome divided. *D*, each germ nucleus resolved into chromosomes; attraction sphere (*a*) double. *E*, mitotic figure forming for the first cleavage; the chromosomes (*c*) already split. *F*, first cleavage in progress, showing divergence of the daughter chromosomes toward the spindle poles (only three chromosomes shown). (Wilson.)

where it immediately loses its characteristic form and develops into a typical nucleus (Fig. 254). The ovum now has two nuclei, one of which is called the male pronucleus, the other the female pronucleus. These both form chromosomes, the number from each being half the number typical of the species. These are arranged as usual between the centrosomes. They divide longitudinally, each forming two, one of which passes to either centrosome, where a new nucleus is formed, and in the meantime the cytoplasm has divided so that two cells are formed. The nuclear material of these two cells has therefore been equally derived from the two parents, and it is to control all of the future development of the individual.

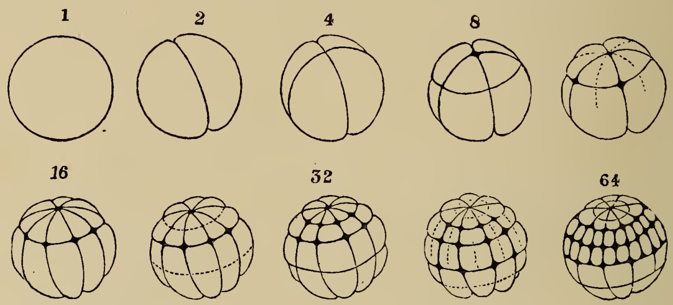


Fig. 255.—Holoblastic segmentation. Segmentation of frog diagrammatically represented.

SEGMENTATION.

Holoblastic Segmentation.—An idea of the development of the embryo can perhaps best be obtained by following the development of the frog. The frog's eggs are large and easily observed, and they contain only a small amount of yolk or food material, which does not obstruct the observation. The spherical ovum first divides into hemispheres; these two cells are divided into four in a plane at right angles, and the four are divided into eight by a plane at right angles to the previous plane. This is best understood by examining the illustration (Fig. 255).

The lines of cell division proceed in a regular way, the planes passing in such direction as to multiply the number of cells by two in each set of divisions. Very soon the cells around the black pole show a tendency to divide more rapidly than those at the white pole. At this stage the individual is made up of a hollow sphere of cells with a space at the center, the cells at the upper surface being small and rapidly dividing, those at the lower surface large and slowly dividing (Fig. 256). As this continues the sphere becomes flattened on the bottom, and finally the lower surface is turned inward until the sphere is converted into a hollow bag or sac made up of two layers of cells, the outer of which are small, the inner

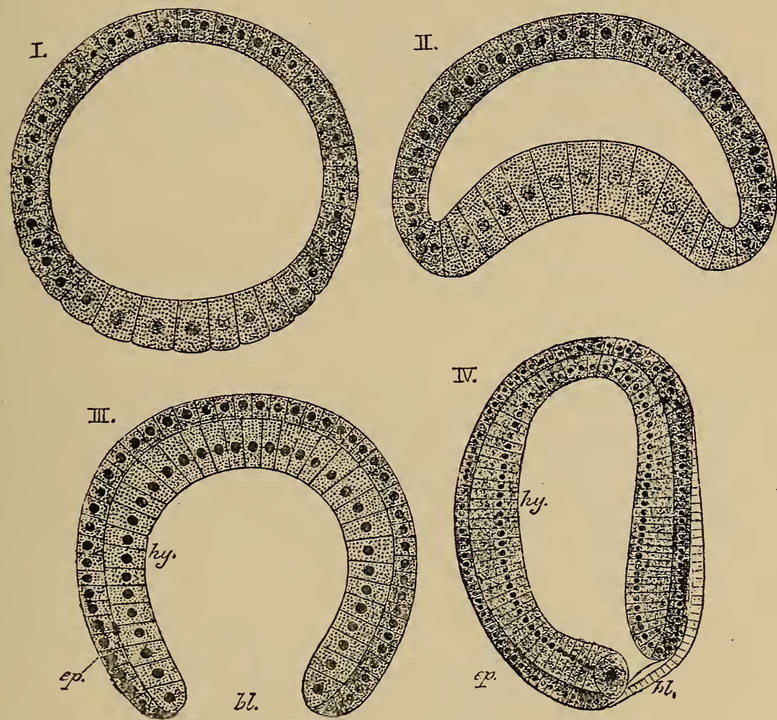


FIG. 256.—Four stages in the development of amphioxus, illustrating the formation of the gastrula. I, the blastula, a hollow sphere of cells; those at the lower pole larger than those at the upper and filled with yolk granules. II, invagination of the lower pole, because of more rapid growth of cells at the upper pole. III, the gastrula, complete invagination; the creature is now a two-layered bag. A space should be shown between the layers: *bl*, the mouth of the bag, or blastopore; *hy*, inner layer of cells—hypoblast; *ep*, outer layer of cells—epiblast. IV, the gastrula will now elongate; the cavity becomes the alimentary canal; the blastopore the orifice at one end.

large, the two joining around the mouth of the sac. This hollow bag stage is known as the gastrula. The cavity of the sac is really a part of the outside world around which the cells have grown, and will form the cavity of the alimentary canal. The opening of the sac is known as the blastopore, and will form the anterior opening into the alimentary tract from the mouth cavity. At this stage the individual is made up of two kinds of cells, and is to be compared in structure with the celenterates or such animals as the fresh-water hydra and the coral polyp.

Formation of the Germ Layers.—The cells which form the outer layer of the gastrula are called the epiblast, the cells which line it the hypoblast or entoblast. Where these two layers join around the opening of the blastopore a ring of cells is formed which differs from both in form and arrangement, and will form the mesoblast. In the process of cell division from the ovum, therefore, three kinds of cells have resulted which represent the first stage of specialization.

Epiblast.—From the cells of the epiblast will be formed: (1) The epithelium of the surface of the body and all glands that connect with it, the hair, the nails, and the enamel of the teeth; (2) the epithelium lining the mouth and the nose cavities and the lower part of the rectum; (3) the nervous system and all of the organs of special sense.

Hypoblast.—From the hypoblast will be formed: (1) The epithelium lining the alimentary canal and the glands that open from it; (2) the epithelium lining the larynx, trachea, and the lungs; (3) the epithelium of the bladder and ureter.

Mesoblast.—From the mesoblast will be formed: (1) The various connective tissues, including bone, dentin, and cementum; (2) the muscles, both striated and unstriated; (3) the circulatory system, including the blood itself and the lymphatics; (4) the lining membrane of the serous cavities of the body; (5) the kidney; (6) the internal organs of reproduction.

Looking at these germ layers in another way, it may be said that through the mechanism of cell division all of the chromatin which is to control nerve cytoplasm has been distributed to the epiblast; all that which is to contribute the muscular activity to the mesoblast, and so on.

Meroblastic Segmentation.—If the development of the chick is compared to that of the frog they at first seem to be very different. The ova of birds and reptiles are provided with a vast amount of food material or yolk, which is provided by the parent for the nourishment of the embryo. It has been seen that the frog's egg contains a certain amount of yolk, and that the presence of yolk granules retarded the cell division. In the case of the birds and reptiles the yolk granules have increased until the active cytoplasm is left as a small disk floating on top of a sphere of yolk enclosed in the yolk membrane. The white spot seen floating on the top of the yolk of a hen's egg is called the germinal spot. Before fertili-

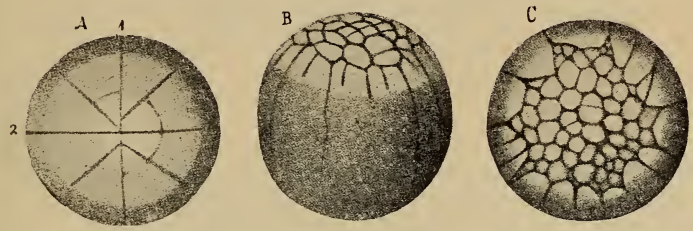


Fig. 257.—Meroblastic segmentation.

zation this is a mass of protoplasm with a nucleus in the center. When segmentation begins it divides first into right and left halves,

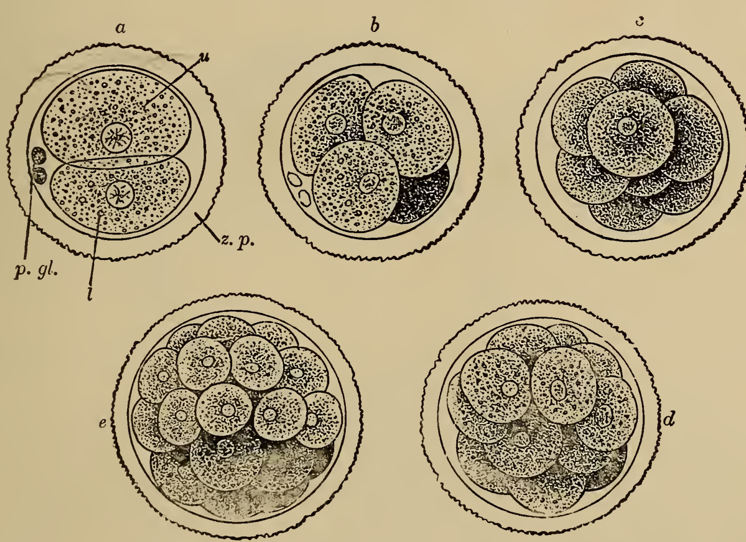


Fig. 258.—First five stages of segmentation (rabbit's ovum), *a*, *b*, *c*, *d*, and *e*. In *a*, *b*, and *c* the epiblast cells are larger than the hypoblastic ones. In *e* the epiblast cells have become smaller and more numerous than the hypoblasts and the epiblastic spheres are beginning to surround and close in the hypoblast cells: *z.p.*, zona pellucida; *p.gl.*, polar globules; *u*, first epiblast cell; *l*, first hypoblast cell.

then divides again by a line at right angles to the first one, then the four cells are converted into eight cells, as if by a circle, and the process continues in this way (Fig. 257). It is best understood from the diagram. This type of segmentation is known as meroblastic, while that of the frog is holoblastic.

Mammalian Segmentation.—The mammalian ova contain very little yolk, as the nourishment of the embryo is provided for in an entirely different way. The segmentation is holoblastic (Fig.

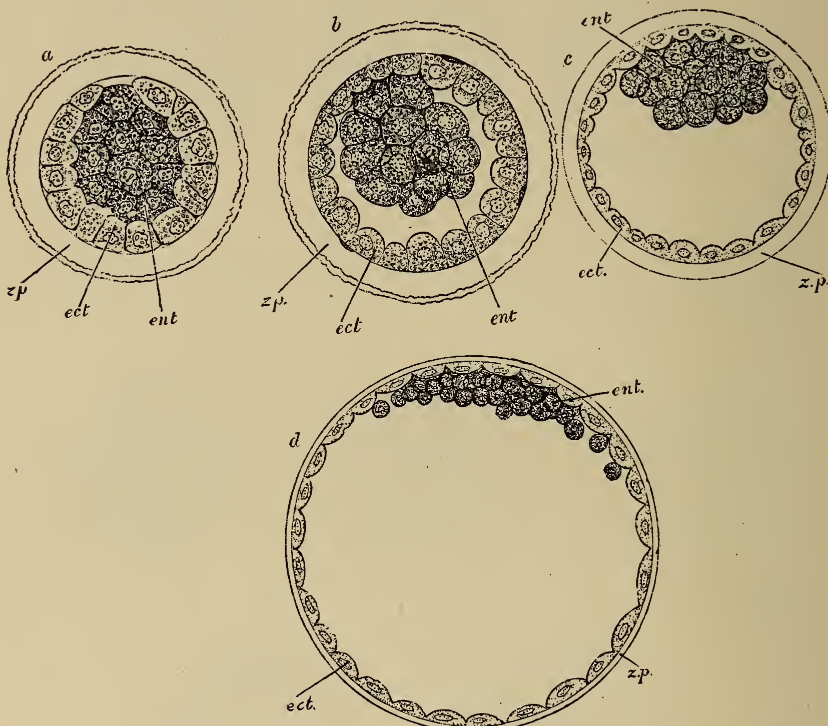


Fig. 259.—Sections of the ovum of a rabbit during the later stages of segmentation, showing the formation of the blastodermic vesicle: *a*, gastrula stages; *ent*, hypoblast enclosed by *ep*, epiblast; *b*, fluid is beginning to collect and separate the epiblast and hypoblast; *c*, the fluid has greatly increased in amount, the hypoblastic cells adhering to the upper surface; *d*, the blastodermic vesicle; *ect*, the outer layer, epiblast; *ent*, hypoblast, the inner layer adhering to the inner surface of the epiblast at the upper surface, forming the opaque area.

258), but shows marked differences from that of the frog, and characteristics similar to those of the birds and reptiles, and this has been an added link to the evidence of the evolutionists, that the mammalia have been derived in evolution from the reptiles.

After the first few divisions the cells of the upper pole divide much more rapidly than those of the lower, and grow down over

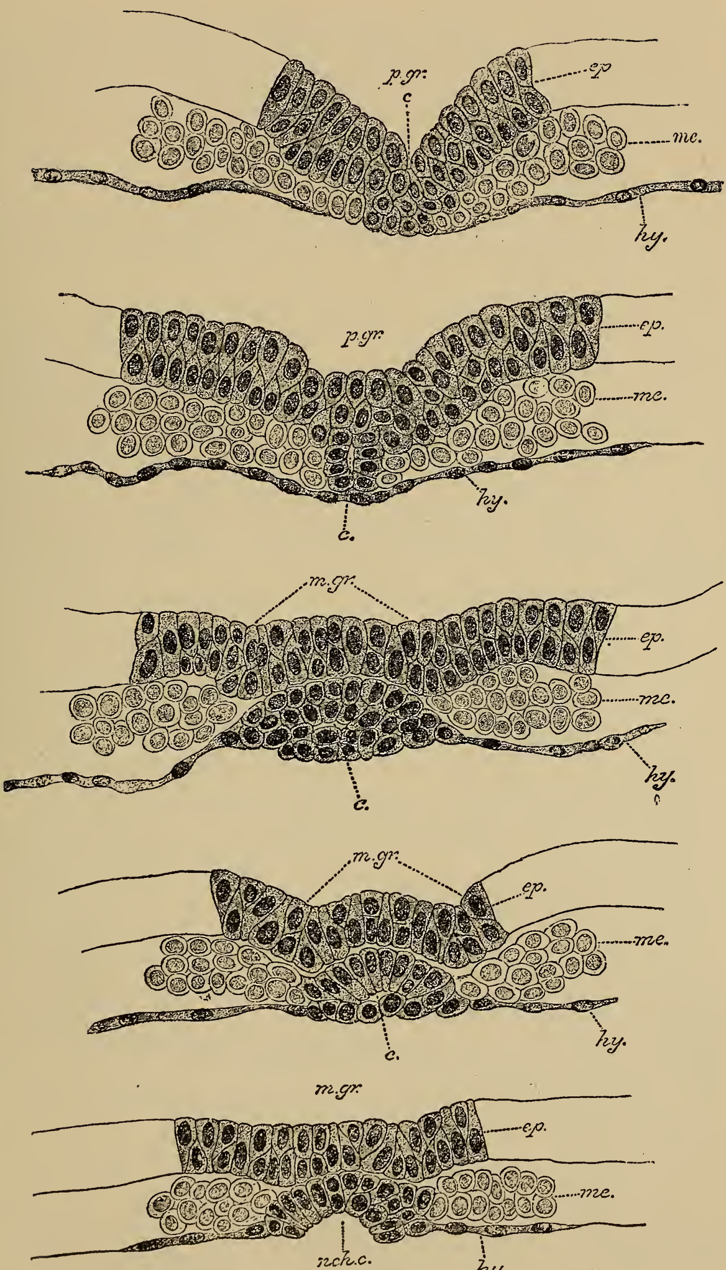


FIG. 260.—A series of sections through the neurenteric and notochordal canal of a mole embryo: *p.gr.*, the primitive groove; *ep.*, epiblast; *me.*, mesoblast; *hy.*, hypoblast; *m.gr.*, medullary groove. (Heap.)

the others, enclosing them. When the large cells have been entirely covered in by the small ones, the small ones continue to multiply more rapidly and fluid collects inside the sphere, leaving the large cells adhering to the inner surface of the small cell layer at one pole of the sphere (Fig. 259). At the upper pole where the sphere is made up of two layers of cells there is an opaque spot, or the "area pellucida," from only part of which the embryo is developed, the rest forming organs to provide it with nourishment during the embryonal condition.

Starting from the center of the opaque area on the upper surface of the sphere or blastula, there appears a streak known as the primitive streak, caused by the appearance of a rod of cells lying between the two layers, and from the side of this rod or notochord a third kind of cell, different from either the large or small cell layer, is formed. These three kinds of cells make up the three layers of the blastoderm and represent the first step in differentiation; or, to state it in a different way, all of the chromatin which (Fig. 260) directs nerve cell activity has been sent to the outer small cell layer, or epiblast, all of the chromatin which directs

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Legend for Plate XX

Figs. 1 to 5.—Diagrammatic representations of longitudinal and cross-sections of hen's egg in various stages of incubation. They illustrate how the embryo is developed out of the area pellucida, and the yolk sac, the serosa, and the allantois out of the extra-embryonal area of the germ layers. The embryo is represented much too large in relation to the yolk sac. The yolk is represented in yellow and the entoderm in green, ectoderm in blue, mesoderm in red, and the black dotted lines indicate the limit to which the inner and outer germ layers have extended over the yolk. The red dots mark the limit of the mesoderm: *ak*, outer germ layer (blue); *mw*, medullary ridges or folds; *N*, neural tube; *am*, amniotic fold; *vof*, *hof*, *saf*, anterior, posterior, and lateral amniotic folds; *A*, amnion, *ah*, amniotic cavity; *S*, serous membrane; *hu*, dermal umbilicus; *sf*, lateral folds; *kf* 1, *kf* 2, head fold; *afb*, *ifb*, outer and inner limb fold; *ik*, inner germ layer (green); *ir*, its margin of overgrowth; *dr*, intestinal groove; *dg*, vitelline duct; *al*, allantois; *ds*, interstitial sac; *du*, intestinal umbilicus; *mk*, middle germ layer (red); *mk*, parietal layer of mesoderm; *mk*, visceral layer of mesoderm; *st*, lateral limits of the same; *dm*, *vm*, dorsal and ventral mesenteries; *th'*, body cavity; th^1, th^2, embryonic extra-embryonic parts of the same.

Fig. 1.—Cross-section through hen's egg on second day of incubation.

Fig. 2.—Cross-section through hen's egg on third day of incubation.

Fig. 3.—Longitudinal section through hen's egg on third day of incubation.

Fig. 4.—Longitudinal section through hen's egg beginning of fourth day of incubation.

Fig. 5.—Longitudinal section through hen's egg on seventh day of incubation.

Fig. 6.—Cross-section through embryo, first day.

Fig. 7.—Diagrammatic longitudinal section through a selachian embryo.

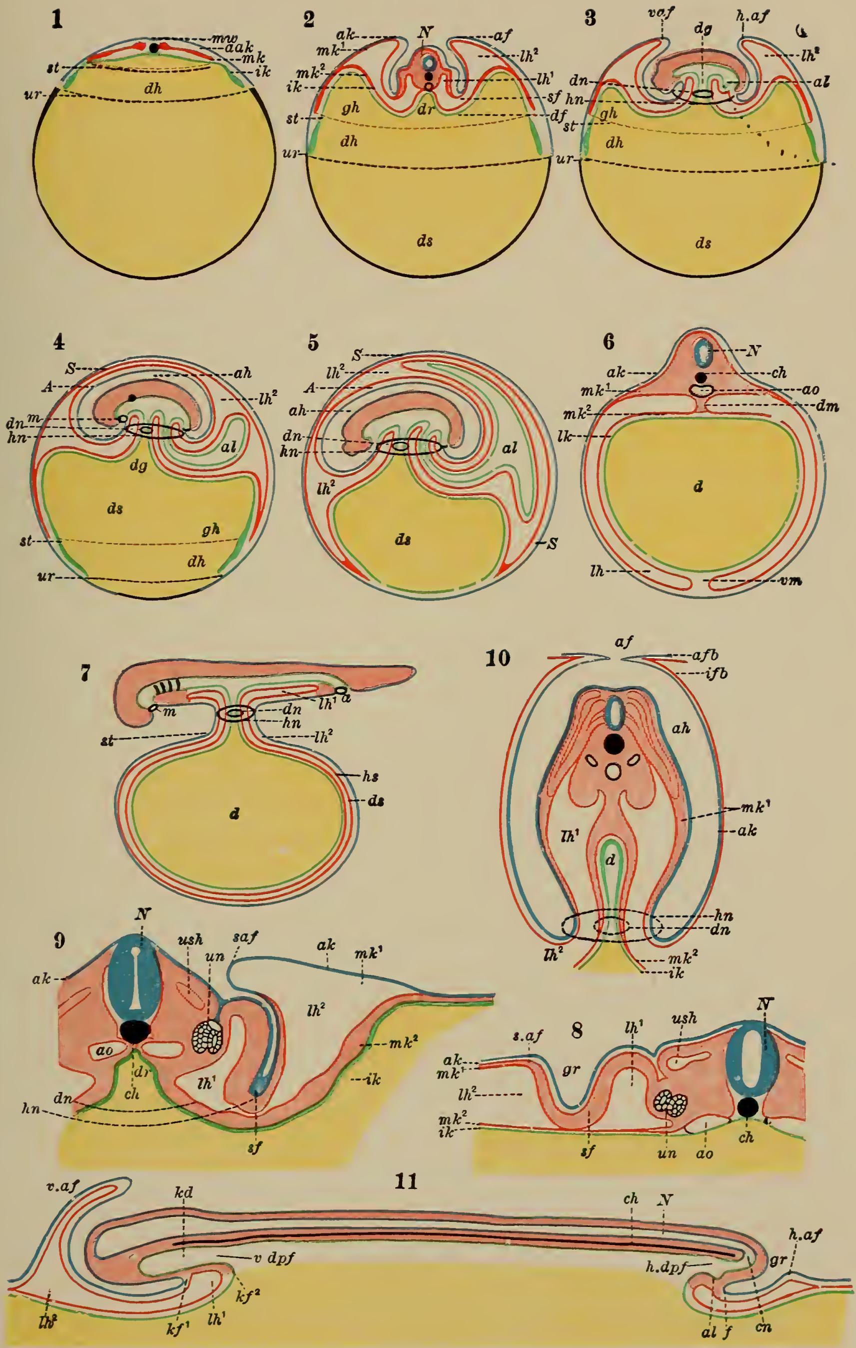
Fig. 8 (Köllikie).—Half of a cross-section through embryo chick (two days.)

Fig. 9 (Köllikie).—Cross-section through embryo chick, beginning of third day.

Fig. 10.—Cross-section of chick (five days) in the region of the umbilicus.

Fig. 11.—Diagrammatic longitudinal section of the embryo chick.

PLATE XX



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muscle cell activity, etc., has been sent to the new cells of the third layer, or mesoblast, while the large cells of the inner layer or hypoblast contain chromatin to direct most of the secretory activities and the formation of the epithelium of the alimentary canal.

NERVOUS SYSTEM.

Formation of Neural Canal.—The epidermal cells of either side of the primitive streak grow rapidly, forming two ridges with a groove between them, which grows deeper and deeper until the ridges bend over and join, enclosing a tube which is to be the canal of the spinal cord (Fig. 261). The anterior end of this tube enlarges into three bulbs which correspond to the ventricles of the brain, and as they increase in size they fold over ventrally or toward the center of the sphere until the first and second are at right angles to the original tubular part.

As the outer layer forms the tube of the central nervous system, the inner layer folds off a blind pouch from the general cavity of the sphere which is to form the anterior part of the alimentary canal (Plate XX). By this time development is complicated by the formation of the embryonal membranes, the amnion and allantois, but we may omit these entirely for our purposes.

The diagram from Quain's *Anatomy* (Figs. 262 and 263) illustrates the condition just described, showing the embryo in longitudinal section, the bending over of the anterior end of the neural canal to form the mid- and forebrain and the foregut, or esophagus, a blind pouch ending anteriorly under the midbrain and posteriorly opening into the cavity of the sphere now called the yolk sac. This pouch is lined by hypoblast and covered by mesoblast and epiblast. The heart has already begun its development in the mesoblast on the ventral side of the foregut.

Branchial Arches.—There now appear what are called the gill slits, openings from the foregut through its walls to the surface of the embryo, which are separated by thickenings of the wall forming arches around the gut known as the visceral or branchial arches, at the center of each of which is found a bloodvessel. These structures are to be compared to the gills of a fish, which are slits through the wall of the esophagus to the outside, so that water taken into the mouth may pass out through the slits. At this time, too, the arrangement of the bloodvessels exactly resembles that of a fish, and the individual may be said to be in the fish stage of development.

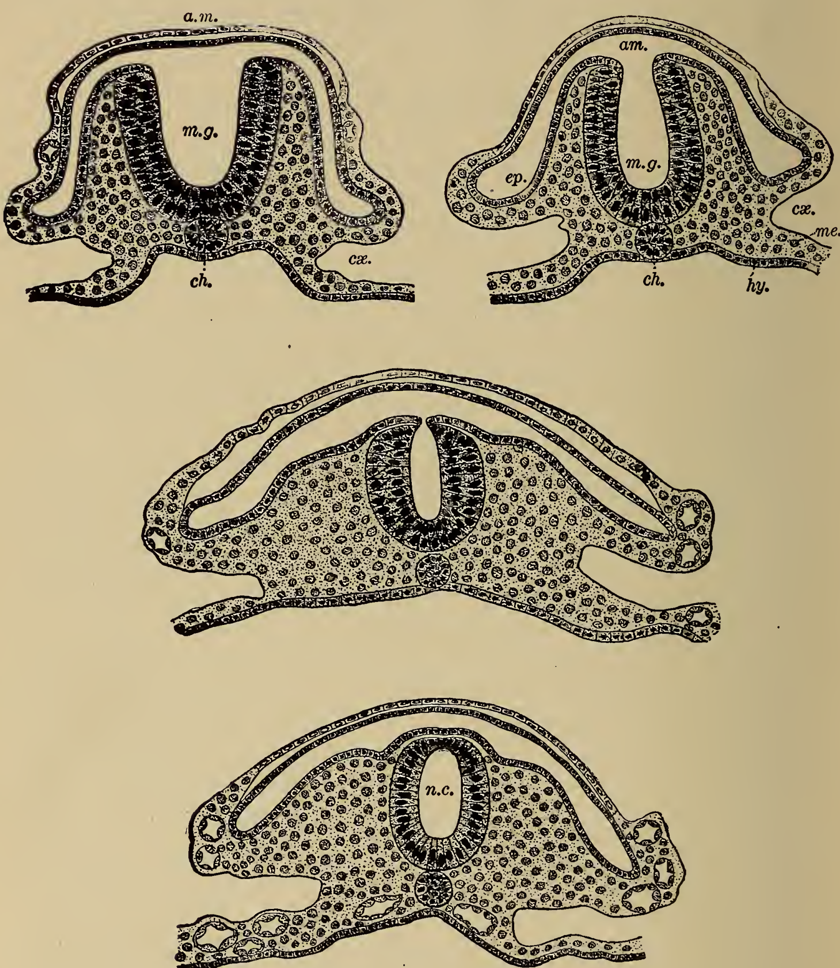
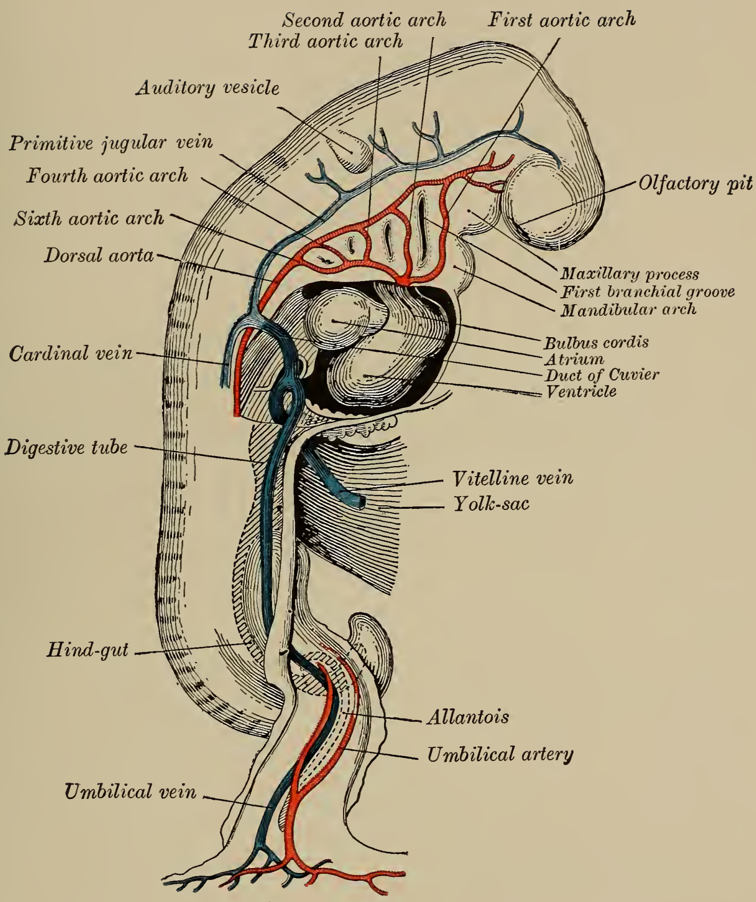


FIG. 261.—Stages in the conversion of the medullary groove into the neural canal. From tail end of embryo of the cat: *m.g.*, medullary groove; *n.c.*, neural canal; *ch.*, notochord; *ep.*, epiblast; *hy.*, hypoblast; *me.*, mesoblast; *cæ.*, celom; *am.*, amnion. (After Quain.)

Stomodeum.—Plate XXI, from Quain's *Anatomy,* and Fig. 264, from Hertwig's *Text-book of Embryology,* shows the embryo at this stage and the arrangement of the bloodvessels. As the fore-

PLATE XXI



Profile View of a Human Embryo Estimated at Twenty-one Days Old. (After His.)

Showing branchial arches and relation to bloodvessels.

brain grows ventrally, the first visceral arch, or mandibular arch, also grows in the same direction, and the space between the inferior surface of the forebrain and the upper surface of the first arch is the beginning of the mouth and nose cavities, now called the stomodeum. From the base of the mandibular arch is seen also the rounded bud, which is beginning to grow forward along the base of the forebrain to form part of the maxillary arch, and finally the upper jaw. At this time also the area which is to develop the

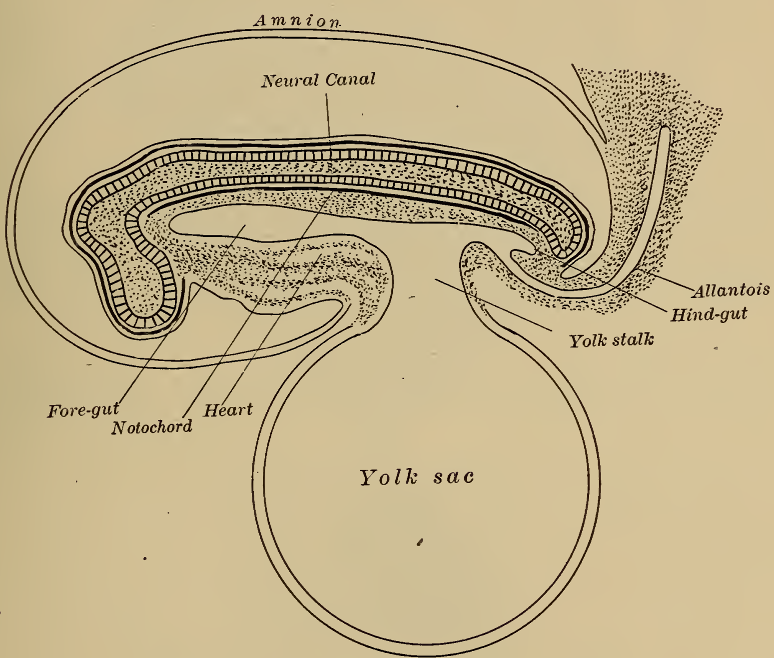


Fig. 262.—Diagram of a longitudinal section of a mammalian embryo. Very early, showing the folding off of the embryo. (After Quain.)

sense of smell appears on each side at the outer and lower portion of the forebrain. The olfactory areas grow out of the base of the forebrain, at first being on the outside of the head and in the later development being enclosed, leaving an opening to the surface—the nostril.

If we have gained a correct idea of the conditions just described by means of the pictures, it will be understood that by the growing forward of the mandibular arch there is left an almost cubical space between the lower surface of the fore- and midbrain and the upper surface of the mandibular arch (Fig. 264). This is a part

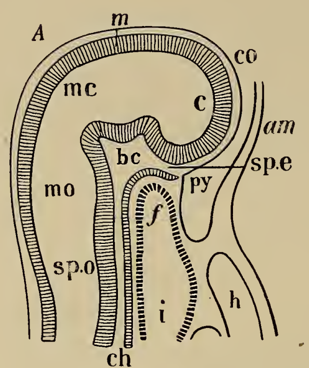


Fig. 263.—Median sections through the head of embryo rabbits five (*A*) and six (*B*) millimeters long: *A*, the opening from the foregut has not yet been made; *B*, the faucial opening is shown at *f*; *c*, first brain vesicle; *mc*, midbrain vesicle; *mo*, medulla oblongata; *m*, medullary epiblast; *if*, infundibulum; *sp.e*, sphenoethnoidal, *bc*, sphenoidal, and *sp.o*, spheno-occipital parts of the basal cranii; *i*, foregut; *ch*, notochord; *py*, buccal pituitary involution; *am*, amnion; *h*, heart.

of the outside world, and is enclosed to form the mouth and nose cavities. This process is best understood if we think of the develop-

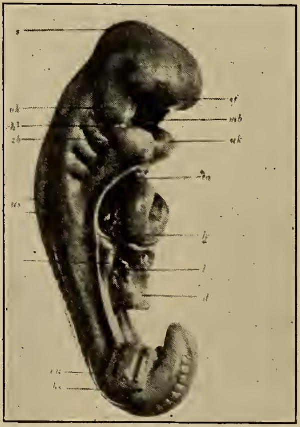


Fig. 264.—Embryo showing brachial arches and stomodeum.

ment from the anterior end of the forebrain of a process which may be described as a curtain dropping down, making a central piece, and the bud from the mandibular arch on each side growing forward to unite with it, leaving a slit between them and the man-

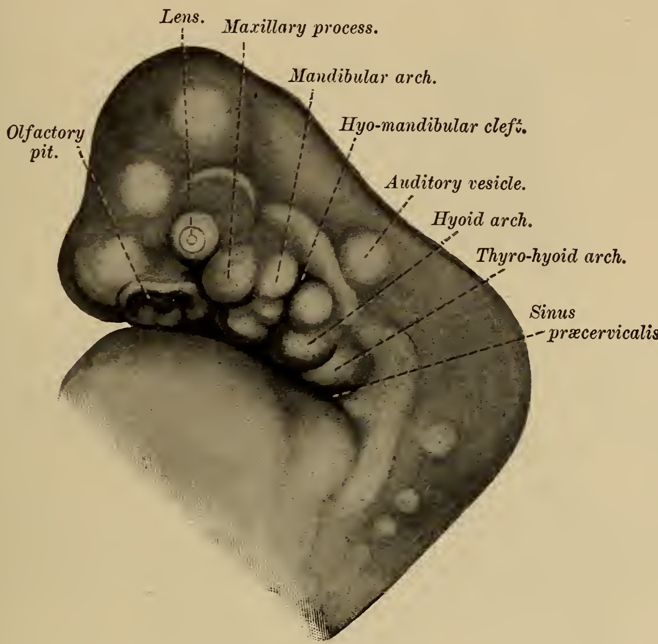


FIG. 265.—The beginning of the mandibular arch and the maxillary buds.

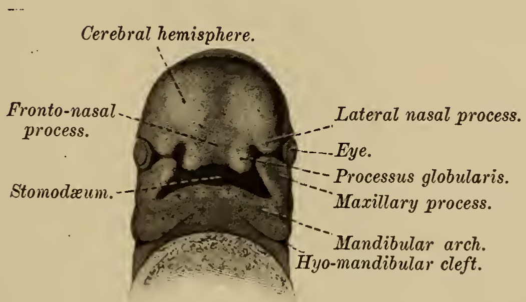


FIG. 266.—An embryo a little older than Fig. 265. Viewed from in front. Showing development of maxillary buds and frontonasal process.

dibular arch which will be the mouth. In order to get a correct idea of this process it must be followed somewhat more minutely.

Frontonasal Process.—As the frontonasal process develops it is made up of four rather bulb-like portions (Figs. 265 and 266),

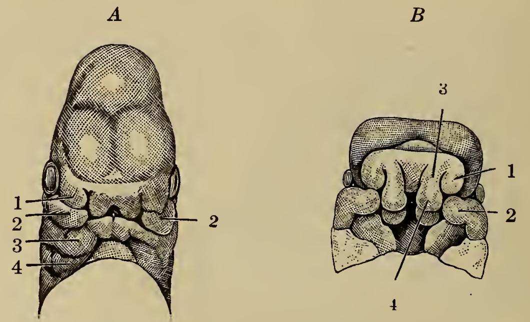


FIG. 267.—Embryo, a little older than Fig. 266. *A*, front view, frontonasal process, and maxillary buds about to unite: *1*, lateral nasal part of frontonasal process; *2*, maxillary bud; *3*, mandibular arch; *4*, hyoid arch. *B*, the same embryo with the mandibular arch removed: *1*, horizontal growth of the maxillary bud; *2*, lateral nasal process; *3*, mesial nasal process; *4*, globular processes which form the horizontal part of the intermaxillary bone.

two occupying the center and which develop into the intermaxillary bone containing the incisor teeth and the center of the lip; and two side or lateral processes which grow out around the olfac-

FIG. 268.—Head of an embryo of about seven weeks. (His.) The external nasal processes have united with the maxillary and globular processes to shut off the olfactory pit from the orifice of the mouth.

tory area and form the alæ of the nose surrounding the nostril. These do not unite again with the central parts, but the end stops over the point where the maxillary bud unites with the central process (Figs. 266 and 267). A failure of union causes the deformity of hare-lip, the opening in the lip extending to one, or, if double, to both nostrils.

When the central part of the frontonasal process has united with the maxillary bud on each side the arch of the upper jaw is complete and the original cubical space or stomodeum is enclosed, leaving only the slit between the maxillary and mandibulary arches which is to form the mouth; but the enclosed space is in one chamber, there being no separation between the mouth and nose cavities.

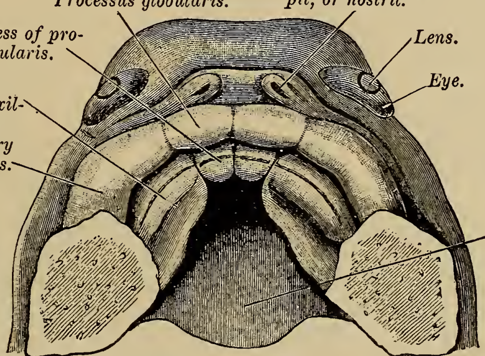


FIG. 269.—The head of an embryo with the mandibular arch removed. Looking up from the mouth into the nose cavity. The union of the globular processes forming the anterior part of the palate, and the horizontal ingrowths from the maxillary buds, showing the way in which they unite from before backward, separating the nose from the mouth cavity.

The time of this development in the human embryo may be placed at about the fourth week.

Separation of Mouth and Nose Cavity.—The separation of the mouth and nose cavities occurs by the development of horizontal ingrowths from the three parts making up the maxilla and beginning at the center and progressing backward. First, a small triangular piece from the central part of globular processes of the frontonasal process, this uniting with the horizontal or palatal process of the maxillary buds on each side until these reach the apex of the triangle, which will be the intermaxillary bone, just a little way back in the palate, and from here backward they unite with their fellow of the opposite side. This is best seen by removing the mandibular arch and viewing the parts from below (Fig. 269, from Hertwig's *Embryology*).

The deformity of cleft palate is then a later development than that of hare-lip, and either may occur without the other, though they are usually found together. The cleft of the palate usually turns to one side at the front, running out between the cuspid and lateral unless it is double, when a detached piece is found in the center in front, containing the incisors. As soon as the mouth and nose cavities are separated and as fast as bone is formed in the jaws most of the space is occupied by the tooth germs.

CHAPTER XXVI.

THE DEVELOPMENT OF THE TOOTH GERM.

The Dental Ridge.—By the middle of the second month of development the arches of both upper and lower jaws are completed, and the palate has separated the nose and mouth cavities. The first indication of the development of the teeth is the multiplication of the cells

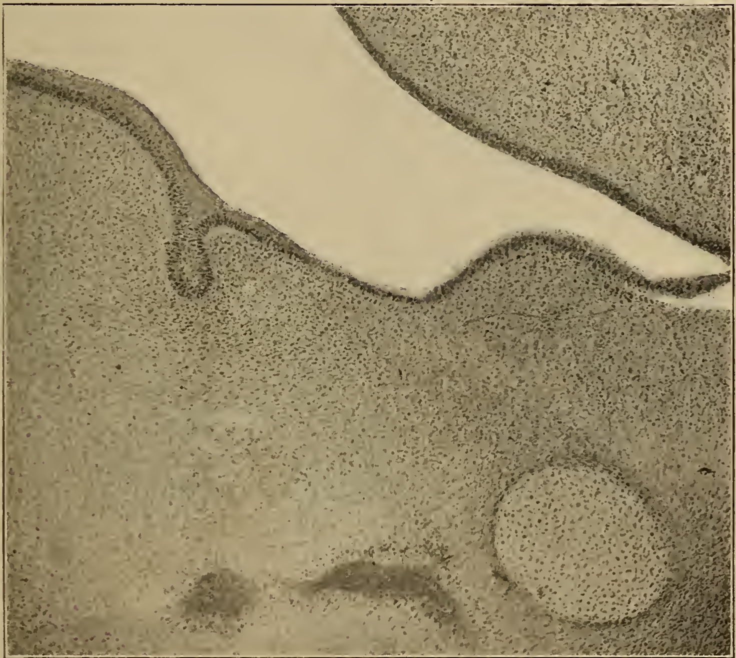


Fig. 270.—The dental ridge. A section through the mandible of a pig embryo at the lower edge, two spicules of bone beginning to form; to the right Meckel's cartilage.

of the epiblast in a curved line on the crest of each arch in the area which is to be occupied by the teeth. By this multiplication of cells the epiderm is piled up in a ridge, projecting above the surface, and at the same time the deep layer of the epiblast is forced down into the underlying mesoderm (Fig. 270). This structure is known as the dental ridge. In sections the cells piled up above the surface are usually washed off more or less by the reagents, but the depression into the mesoderm is shown. On the lingual surface of this ridge, in the part embedded in the mesoderm, the cells of the Malpighian layer grow out lingually at right angles to the ridge, forming a continuous shelf known as the *dental lamina* (Fig. 271). It is important to remember that the lamina is continuous along the entire extent of the ridge.

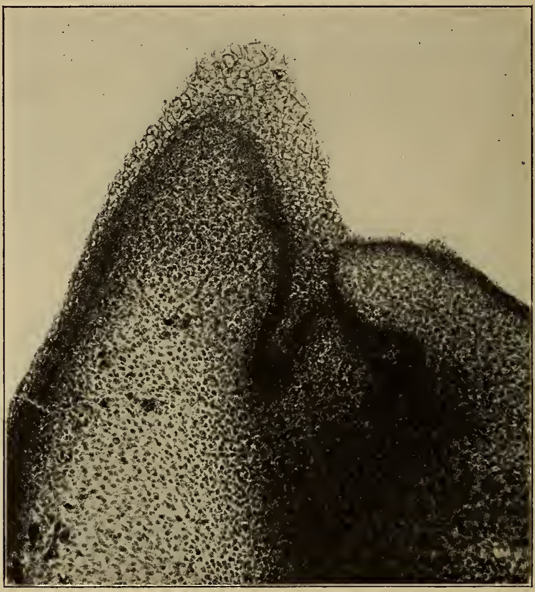


Fig. 271.—The dental ridge and dental lamina.

The Enamel Organ.—From ten points on the surface of the lamina little buds of epiblast start and grow down into the mesoderm, increasing in size and becoming bulbous at the deep end. The bulbous portion gradually becomes flattened. At this stage the bulb is composed of an outer layer of columnar cells, continuous with the Malpighian layer of the ridge and a central mass of large polyhedral cells (Fig. 272). As the bud continues to grow into the mesoderm, the mesodermic tissue below it begins to condense and the cells of the upper portion of the bulb, growing more rapidly, convert the bulb into a two-layered bag.

The Dental Papillæ.—The cells in the condensed mesoderm multiply and grow up into the cavity of this cap, forming the beginning of the dental papillæ. This stage is represented in Figs. 273 and 274, in which the enamel organ is seen connected with the lamina by a cord of epithelial cells, and made up of an outer layer of columnar cells known as the *outer tunic,* and an inner layer of columnar cells lying next to the dental papillæ, known as the *inner tunic.* The polyhedral cells between the two layers fill the central part of the enamel organ and have taken on a peculiar appearance, which has given to them the name of the *stellate reticulum.* The

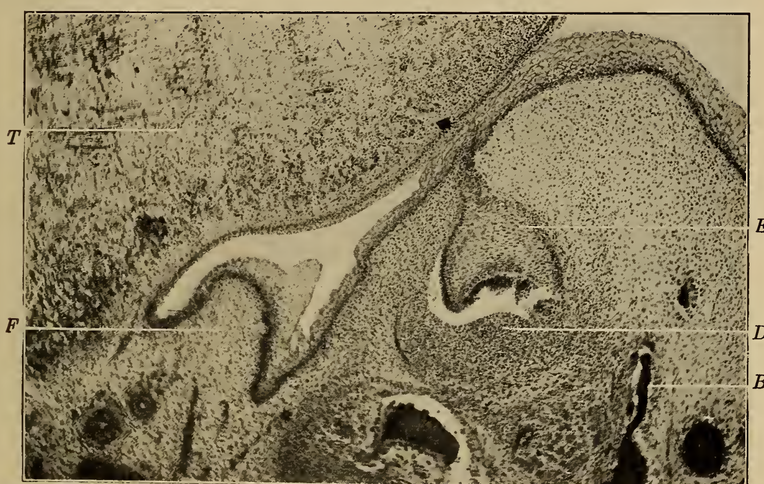


FIG. 272.—A section through the mandibular arch: *E*, enamel organ; *D*, beginning of the dental papilla; *B*, bone; *F*, fold from the side of the mandible to the base of the tongue covering the beginning of the sublingual gland; *T*, tongue.

development of the tooth germ now progresses until the dental papilla has taken on the typical form of the tooth. The fully formed enamel organ for an incisor of a sheep is shown in Fig. 275. The cord which connects the outer tunic with the surface epithelium is not shown in this section.

The Tooth Germ.—The tooth germ is composed of the enamel organ, made up of the *outer tunic,* the *inner tunic,* and the *stellate reticulum,* covering the *dental papillæ.* From the base of the papillæ fibrous tissue develops, growing upward around the entire tooth germ and enclosing it in a definite wall or sac of fibrous tissue. This is known as the *dental follicle,* or the follicle wall.

The Dental Follicle.—This term has been used to indicate not simply the connective-tissue wall, but all of the structure enclosed in it. This use of the term, however, is confusing, and the term should be confined to the fibrous sac. By the end of the twelfth week the follicle wall has grown up so as to enclose the enamel

FIG. 273.—The enamel organ. The outer tunic connected to the lamina by the cord; the dental papilla growing up into the cap. The spaces are shrinkage spaces.

organ, and the epithelial cord which has connected it with the surface is broken.

Tooth Germs of the Permanent Tooth.—Before the epithelial cord is broken, from some point on the lingual surface of the outer tunic or along the cord a bud of epithelial cells grows out and turns down into the mesoderm, passing over the follicle wall (Fig. 276). This continues to grow downward until it has reached the position below and to the lingual of the tooth germ for the temporary tooth, where it develops into the enamel organ for the corresponding permanent tooth. It goes through the same changes of form as has been seen in the temporary teeth.

Beginning of Calcification.—About the sixteenth week the tooth germs of all the temporary teeth have been completely enclosed in their follicles and the enamel organ for the corresponding permanent teeth have begun their development (Fig. 277). This illustration shows a section through the lower jaw of a pig, and

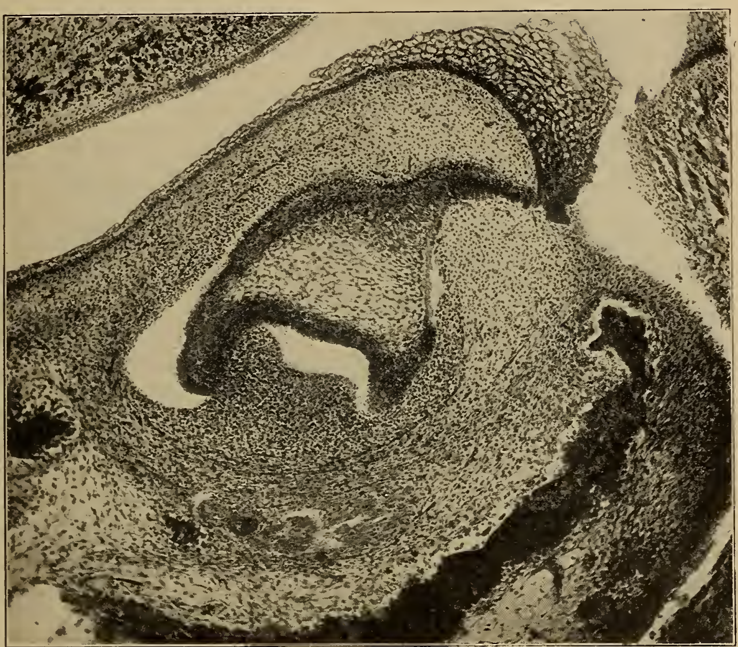


Fig. 274.—The enamel organ, a little older than Fig. 273. It shows the outer tunic, the inner tunic, and the stellate reticulum. The dental papilla in the hollow of the cap. The spaces are caused by shrinkage.

exhibits the tooth germs for two incisors at about the stage of the closing of the follicle walls. The buds for the permanent teeth are seen on the lingual, and the formation of enamel and dentin is just beginning in the temporary teeth. Notice the remains of Meckel's cartilage, and the extension of endomembranous bone formation which is just beginning to form a periosteum on its surface. The bone has grown around Meckel's cartilage and around the tooth germs on the buccal and lingual, enclosing them in an open groove, which will later be completed and divided into separate crypts for each tooth. Fig. 278 is from a similar specimen in the region of a temporary molar. The dental papilla is taking on the form of a crown and the formation of enamel and dentin is ready to begin. The cells on the outer layer of the dental papilla have developed into odontoblasts, forming a single layer of columnar

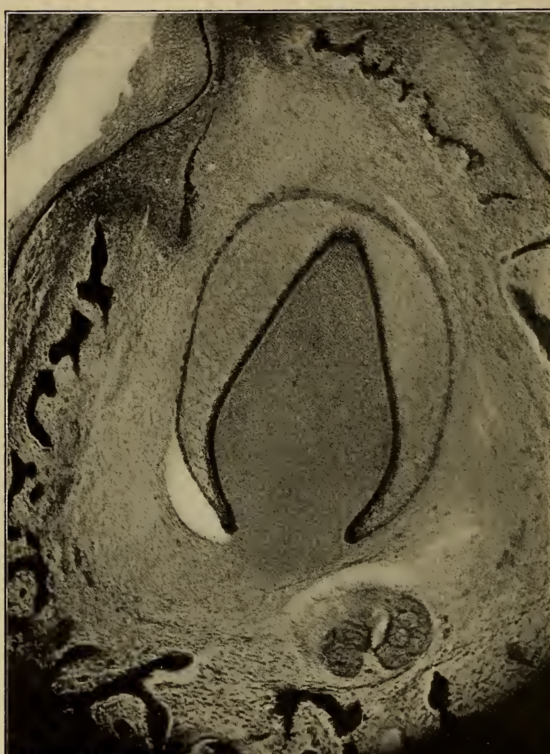


Fig. 275.—The tooth germ, from the mandible of a sheep. The enamel organ shows the outer tunic, inner tunic, and stellate reticulum. The dental papilla projects into the enamel organ. The follicle is attached to the base of the dental papilla and surrounds the enamel organ. The spicules of bone form the crypt wall.

cells lying in contact with the inner tunica of the enamel organ. Here the formation of enamel and dentin begins, the dentin slightly preceding the enamel. The odontoblasts form and calcify dentin matrix from without inward. The cells of the inner tunic or ameloblasts form and calcify the enamel rods and cementing substance, progressing from within outward. The line upon which the odontoblasts and ameloblasts lie in contact therefore will become the dento-enamel junction. The formation of dentin and enamel begin at separate points, which are at first very close together, but are

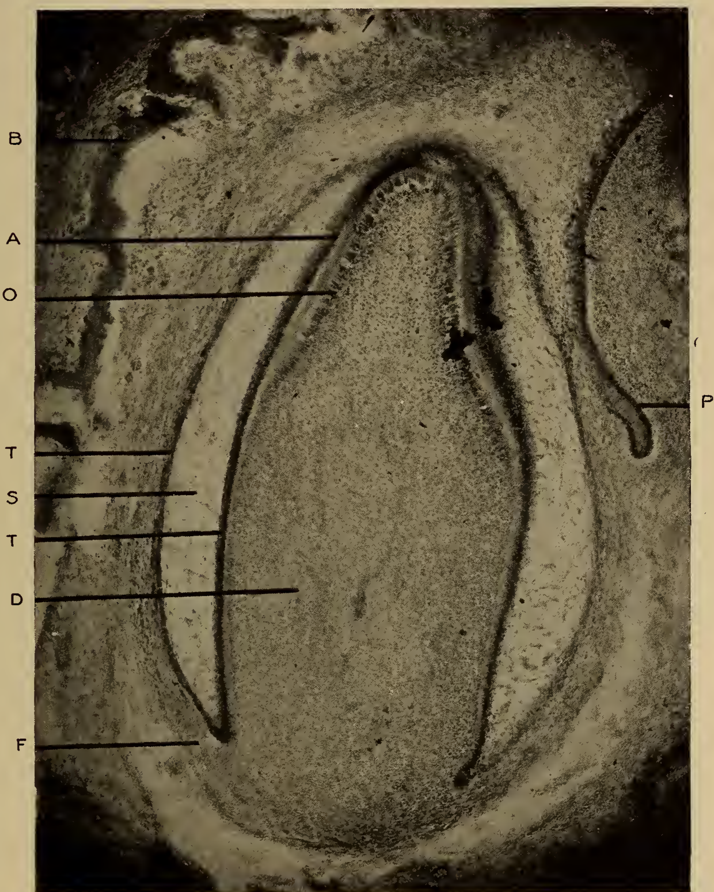


FIG. 276.—The tooth germ showing the bud for the permanent tooth at *P*. Calcification is just beginning: *F*, follicle wall; *D*, dental papilla; *T*, inner tunic; *T′*, outer tunic; *S*, stellate reticulum; *O*, odontoblasts; *A*, ameloblasts; *B*, bone.

carried farther apart by the growth of the dental papilla, until they have progressed along the dento-enamel junction and unite, when the increase in the diameter of the dental papilla is stopped. This, perhaps, will be better understood by studying Figs. 82 to 87.

First Permanent Molar.—The origin and development of the first permanent molar differs from that of all the other permanent

FIG. 277.—A section through the lower jaw of a embryo pig, showing germs of two incisors.

FIG. 278.—Germ of a premolar from an embryo pig.

Chronology of the Dental Follicle in Man (Legros and Magitot).

	Designation of the follicles.	Place of origin of the epithelial cord.	Period at which the enamel organ first appears.	Period at which the dental bulb appears.	Time of the appearance of the follicular wall.	Closing of the follicle and rupture of the cord.	Periods at which the dentin cap first appears.	Periods at which the teeth are erupted.	Periods at which the teeth are normally shed.
Temporary dentition.	Inf. cent. incisor	....	....	......	......	......	......	6th month	7th year.
	Sup. cent. incisor	....	....	......	......	......	......	10th month	$7\frac{1}{2}$ years.
	Inf. lat. incisor	....	....	......	......	......	16th week	16th month	8th year.
	Sup. lat. incisor	....	....	......	......		......	20th month	
	Inf. cuspids	Epithelial lamina	From 7th to 8th week	9th week	10th week	Beginning of the 4th month	......	30th to the 32d month	12th year.
	Sup. cuspids						......		
	1st inf. molars	....	....	......	......		......	24th month	10th year.
	1st sup. molars	....	....	......	......	......	17th week	26th month	$10\frac{1}{2}$ years.
	2d inf. molars	....	....	......	......	......	......	28th month	11th year.
	2d sup. molars	....	....	......	......	......	......	30th month	$11\frac{1}{2}$ years.
Permanent dentition.	Inf. cent. incisor		....	......	......	......	......	7th year.	
	Sup. cent. incisor	Cord of the corresponding temporary teeth	....	......	......	......	......		
	Inf. lat. incisor		....	......	......	......	......	$8\frac{1}{2}$ years.	
	Sup. lat. incisor		....	......	......	......	......		
	Inf. cuspids		About the 16th week	20th week	21st week	9th month	1st month after birth	11 to 12 years.	
	Sup. cuspids								
	1st inf. bicuspid		....	......	......	......	......	9 to 10 years.	
	1st sup. bicuspid	Cord of the corresponding temporary molars	....	......	......	......	......		
	2d inf. bicuspid		....	......	......	......	......	11th year.	
	2d sup. bicuspid		....	......	......	......	......		
	1st inf. molars	Epithelial lamina	15th week	17th week	18th week	20th week	6th month of fetal life	From 5 to 6 years.	
	1st sup. molars								
	2d inf. molars	Cord of the 1st perm'nt molars	3d mo. after birth	1st year	1st year	1st year	3d year	From 12 to 13 years.	
	2d sup. molars								
	3d inf. molars	Cord of the 2d perm'nt molars	3d year	After the 6th year	After the 6th year	After the 6th year	12th year	From 18 to 25 years.	
	3d sup. molars								

teeth in important respects. It is the only permanent tooth whose enamel organ springs directly from the dental lamina in the same way as those for the temporary teeth. It is the only permanent tooth whose crown is calcified before the individual is thrown upon its own resources for the obtaining of nourishment. Nature seems to have taken special precautions in the formation of this most important tooth.

About the seventeenth week, at a point on the dental lamina, posterior to the enamel organs of the temporary teeth, a bud starts to grow down into the mesoderm, which develops into the enamel organ for the first molar, and by the ninth month the follicle is complete and calcification has begun.

The Origin of the Second and Third Molars.—The enamel organ for the second molar is formed from a bud given off from the outer tunic of the enamel organ of the first molar. The enamel organ for the third molar is formed from a bud given off from the outer tunic of the enamel organ of the second, at about the third year.

Chronology.—The development of the teeth was first investigated by Lagros and Magitot (about 1865). Since that time their work has been repeated and verified by several investigators. About 1880 Dr. Black repeated the entire work of Magitot, and some of his illustrations were used by Dr. Dean in his *Translation of Magitot Memoir*. Magitot's table, showing the chronology of tooth development, is given on page 329.

The previous pages are to be considered as a series of definitions, and descriptions of structures, and now the student is assumed to have some idea of what is meant when the "dental ridge," or the "dental papilla" is mentioned.

In embryology so many things are going on at the same time and the changes are so rapid that it is difficult, especially from written description, to obtain a clear idea of the process. Unfortunately a moving picture of the development of the tooth cannot be made by direct photography as has been done with the growth of plants and the opening of flowers, but it is important to visualize the process as would be done by a moving picture, the present description is intended to connect and relate in a most elementary way some of the most important facts.

The First Indication of Tooth Development.—The first indication of tooth development is the multiplication of epidermal cells about the maxillary and mandibular arches. This produces a cord or rod of epiblastic cells projecting above the surface of the jaw arch and extending into the mesoderm of the body of the arch. The extension into the mesoderm is more or less vertical to the surface of the primitive jaw. This is the "dental ridge." On the lingual side of this structure the epidermal cells grow out forming a layer or shelf projecting from the lingual side of the ridge and extending as far as the ridge itself. This newgrowth is at first nearly at right angles to the axis of the ridge, but the tip of it turns down into the mesoderm, becoming more and more parallel with the axis of the original dental ridge. This is the "dental lamina."

Early in the development of the lamina at ten points in each arch, epidermal buds start from the edge of the lamina to form the enamel organs for the ten temporary teeth. When these buds start they are springing from the edge of the lamina, but after the formation of the enamel organs for the temporary teeth has started the growth of the lamina continues growing down to the lingual of the developing temporary tooth germs. The extent and continuity of this development seems to be different in different species. A true mental picture of this process will explain the conflicting statements as to the origin of the enamel organs for the permanent teeth, which correspond to or replace the temporary ones. The enamel organs for these teeth are said by different authors (1) to arise from the outer tunic of the enamel organ of the temporary tooth; (2) from the cord connecting the outer tunic of the temporary tooth with the surface epithelium; (3) or direct from the lamina.

Enamel Organ.—As soon as the enamel organ begins to grow down into the mesoderm. There is a response in the mesoderm below it resulting in a change in the character of the cells, and the development of the dental papilla. The epithelial cells of the inner tunic assume the form of ameloblasts and the mesoblastic cells of the outer surface of the dental papilla become columnæ and take the form of odontoblasts. This specialization begins at the tip of the dental papilla and at the points that will be the beginnings of calcification. This specialization spreads from these points along the surface of the papilla. The formation of enamel begins while the enamel organ is still in its typical form, that is, while the outer tunic is complete and is still connected with the lamina by a cord of epithelial cells, but almost immediately after the formation of enamel and dentin begins, there are important changes.

The Follicle Wall.—As soon as the dental papilla and enamel organ begins to take on their full form, there occurs differentiation of tissue in the mesoderm and the formation of fibrous tissue. This begins at or near the base of the papilla, but rapidly extends upward (incisally) passing outside of the outer tunic inclosing both structures in a fibrous sac. When this formation of fibrous tissue reaches the incisal extremity of the enamel organ and approaches the point from which the cord of epithelial cells extends to the lamina, the cord is broken and the enamel organ is no longer connected with the surface. At this time four important things happen: (1) The beginning of calcification of enamel and dentin; (2) the breaking up of the outer tunic of the enamel organ which begins at the point where the cord was broken; (3) a marked proliferation of epithelial cords and masses arising from the cells which formed the cord; (4) the beginning of the bud to form the enamel organ for the successional tooth.

The Breaking up of the Outer Tunic.—When the follicle wall closes over the incisal extremity of the enamel organ, there appears on the outer surface of the outer tunic of the enamel organ little rounded projections of epithelial cells, and the layer is broken up. At the same time there is the formation of capillary bloodvessels from the follicle wall, which carry the remains of the outer tunic down against the inner tunic to form the stratum intermedium (Fig. 238). There is an intimate relation between capillary bloodvessels and the stratum intermedium. Leon Williams considered that the cells of this layer take up materials from the blood and elaborate them to be used by the ameloblasts in the calcification of enamel. Enamel is formed only as far as the stratum intermedium is formed, although the inner tunic of the enamel organ extends apically along the dental papilla toward the end of the root as far as dentin is formed.

The Breaking up of the Epithelial Cord.—After the closing of the follicle wall the cells which formed the cord multiply and are mixed with fibrous tissue. This is no longer a continuous cord of epithelial cells, but irregular strings and masses of epithelial cells lying in the fibrous tissue. This has been called the cingulum, extending from the follicle wall to the surface epithelium.

It often happens that the epithelial masses take on globular form and it is probable that occasionally one of these may develop into an enamel organ, and lead to the formation of a supernumerary temporary tooth.

The bud for the corresponding permanent tooth grows downward (apically) along the lingual side of the germ of the temporary tooth outside of its follicle wall, until it comes to a position below and to the lingual of it, where it goes through exactly the same changes that have taken place in the development of the temporary one.

At the time the follicle wall closes over the enamel of the permanent tooth there occurs a similar, but usually more marked and extensive proliferation of epithelium, and the origin of supernumerary permanent teeth is so explained. The supernumerary would develop between the temporary and the permanent tooth, and as a rule it is found clinically that in such cases the first tooth to erupt after the loss of the temporary one is the supernumerary and the last one the typical tooth.

Origin of the Second and Third Molars.—If one can visualize the process that has been described it will be realized that it is quite difficult from the appearances of a few sections to determine whether the enamel organs for the second and third molars which have no temporary predecessors arise from a bud from the outer tunic of the preceding (approximating) molar, or whether there is an extension of the lamina distally from which the buds are formed.

CHAPTER XXVII.

THE RELATION OF THE TEETH TO THE DEVELOPMENT OF THE FACE.

At birth the jaws contain all of the temporary teeth and the first molars in a partially-formed condition, and the follicles for all of the permanent teeth except the second and third molars. These very nearly fill the substance of the bone. In the growth of the bones of the face and the changes that occur in the transformation of the child to the adult face, the teeth play a most important role.

Before considering this subject in detail it is necessary to recall in this connection some things that have already been emphasized.

RELATION OF THE TEETH TO THE BONE.

In evolution the teeth originally had no connection with the bone, it being formed later for their support. In embryology the tooth is formed first, and the bone formed around it. In this way the development of the individual repeats evolution. In the study of the bone it has been emphasized that the connective tissues have been specialized to meet mechanical conditions, and that both ontogenetically and phylogenetically they are formed in response to mechanical stimuli. The mutations of connective tissue have been dwelt upon, and especially the fact that a bone as an organ of support always contains fibrous tissue, and that there is a continual oscillation between formation and destruction, by means of which it is perfectly adapted to its mechanical environment. The transformations of bone in bone growth have been pointed out, and these will be still more carefully studied in connection with the growth of the bones of the face.

Some years ago the author undertook a study of the structure and growth of the jaws and alveolar process, which resulted in very important modifications of the conceptions of the matter as given by standard texts. Tomes describes the process of development as essentially an addition at the posterior portions of the jaws to make room for the successively developed permanent molars, and illustrates the process in diagrams (Fig. 279).[1] The following quotation states his view:

"But the main increase in the size of the jaw has been in the direction of backward elongation; in this, as Kölliker first pointed out, the thick articular cartilage plays an important part. The manner in which the jaw is formed might also be described as wasteful; a very large amount of bone is formed which is subsequently, at no distant date, removed again by absorption; or we might compare it to a modelling process, in which thick, comparatively

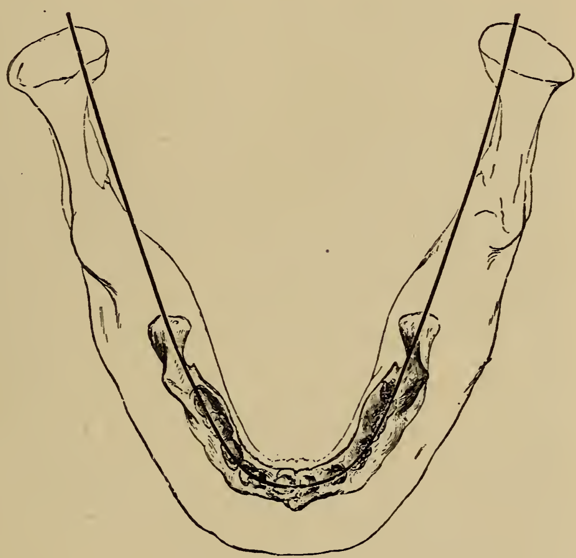


Fig. 279.—Tomes' diagram of development of mandible from infant to adult.

shapeless masses are dabbed on to be trimmed and pared down into form.

"To bring it more clearly home to the student's mind, if all the bone ever formed were to remain, the coronoid process would extend from the condyle to the region of the first bicuspid, and all the teeth behind that would be buried in its base; there would be no neck beneath the condyle, but the internal oblique line would be a thick bar corresponding in width with the condyle. It is necessary to fully realize that the articular surface with its

[1] Tomes' Dental Anatomy, p. 208.

cartilage has successively occupied every spot along this line; and as it progresses backward by the deposition of fresh bone in its cartilage, it had been followed up by the process of absorption, removing all that was redundant."

In a similar way in any maxilla, the temporary dentition is shown to occupy about the same space as the permanent teeth, as far as the second bicuspid, and the adult is supposed to be formed from the child by the building on of the bone at the back as the molars are formed.

This conception is fundamentally misleading, for if the infant mandible were to be shown in the relation to that of the adult in three dimensions of space, it would be found to be above and entirely within the adult mandible, and no part of the bone which constituted the infant jaw is present in the adult. In the upper, if the temporary teeth at two years were figured in relation to those of the adult, they would be placed somewhere up in the nasal cavity.

The conditions are more correctly stated by saying that forces exerted at the posterior portions of the jaw through the development of the successive molars cause the bone to grow downward, forward, and outward in the upper arch, upward, forward, and outward in the lower, carrying the bone into an entirely new position in space.

In this process the peridental membrane, periosteum, and articular cartilage all play their part, but all the bone posterior to the second bicuspid cannot be thought of as having been formed by the articular cartilage and modelled into form by the periosteum, as might be inferred from Tomes' statement.

Structure of Maxillæ and Mandible.—Before attempting to follow the growth of the bone in the development of the face, the arrangement and distribution of the varieties of bone in the structure of the mandible and maxillæ should be carefully studied.

Cortical Plate.—The outer surface of these bones is formed of a compact layer composed partly of subperiosteal and partly of Haversian system bone. This varies greatly in thickness, depending upon the stress to be sustained. It is called the cortical plate.

Cancellous Bone.—The center of the bone is cancellous in character and made up of thin plates of lamellæ arranged around large medullary spaces. The direction and arrangement of these plates is determined by the forces received on the cortical plates and the directions of stress to which they are subjected. This was pointed out some years ago by Walkoff in an elaborate study of the bones by the use of the x-rays. By this means he showed that the plates of cancellous bone in certain areas had a definite arrangement which was related to the attachments of certain muscles. From the examination of sections of the mandible it will be found that not only is the general form of the bone determined by the forces to which it has been subjected, but also that its minute inner structure is definitely arranged with reference to these forces. The direction and arrangement of the plates of cancellous bone are continually

Fig. 280.—The distribution of bone in the alveolar process.

changed and rebuilt to readjust them to the support of new conditions (Fig. 326).

Cribriform Plates.—The alveoli or sockets into which the roots of the teeth fit are bounded by a thin, definite wall, which is pierced by a great many openings. These have been called the cribriform plates, or sieve-like plates. They unite the cortical plates of the bone at the border of the alveolar process, and are fused with it, on their labial and lingual sides. The cribriform plates forming the walls of the alveoli are really made up of a thin layer of subperidental bone, which has been built on to the plates of cancellous bone, to attach the fibers of the peridental membrane (Fig. 213). Within the substance of the bone and surrounding the course of the inferior dental artery and nerve is found what Cryer has called the cribriform tube. This extends from the point where the arteries and vein enter the substance of the bone on the lingual surface of the ramus, posterior to the alveolar process and below the oblique line, and extends through the cancellous portion of the body of the bone, emerging at the mental foramina. It is really a rather definite arrangement of the plates of cancellous bone around the vessels and the nerves.

Fig. 281.—Skull of orang-outang.

Alveolar Process.—If the adult alveolar process as seen in the skull is examined, it is apparent that the bone is arranged so as to give the greatest support with the least possible bulk, and where there is an increase in bulk it is to meet some special force (Fig. 280). The incisors and cuspids are used chiefly to bite off pieces of food, and when the food cannot be bitten it is torn and wrenched away. This puts a heavy strain in all directions on the roots of the teeth, which must be supported by the bone. For this reason the roots of the incisors are usually well covered with bone through their entire length. The cuspid root is long and the upper portion of it so well supported in the bone at the side of the nose and toward the orbit that the most convex portion of it is sometimes uncovered. In animals that use the incisors largely for tearing, wrenching, and fighting, the bone is greatly thickened over the incisal roots, as is shown in the skull of the orang-outang (Fig. 281).

In the upper molars the spreading of the three roots gives abundant support against the direct forces of occlusion. The grinding motions bring lateral pressure against the inclined planes of the cusps, which is met by a thickening of the process in its occlusal

Figs. 282 and 283.—Human mandible, showing form of the bone and the positions from which sections were cut.

third (Fig. 280), forming a heavier ring of bone, while the buccal roots are often exposed in their middle third. In the molars the buccal incline of the lingual cusps of the upper occlude with the lingual incline of the buccal cusps of the lower when the jaws are brought squarely together, and in the grinding motions the outward pressure on the lower molars is supported by the great mass of the

Fig. 284.—Human mandible, showing form of the bone and the positions from which sections were cut.

body of the bone, while the inward pressure is supported by a thickening of the occlusal third, as the entire alveolar process projects lingually from the body of the bone. In the examination of any collection of skulls, the amount and arrangement of the bone of the alveolar process will be found to be an indication of the masticatory habits of the individual.

In examining the sections through the bone of the alveolar process, the adaptation of the arrangement of bone to the force to be sustained should be constantly kept in mind.

Influence of Mechanical Conditions in Evolution.—Professor E. D. Cope,[1] in a long treatise on "The Mechanical Causes of the Development of the Hard Parts in Mammals," has elaborated the fact that the bones of the skeletons of all mammals have been influenced in their development by mechanical conditions, and that their present forms are adaptations to physical environment. In this he states, as a general principle of structure, that the bone is most dense, but least in amount, on the side in the direction toward which forces have been exerted in development, and less dense, but greater in amount, on the sides from which the forces have been exerted. These statements should be applied in the study of all the sections shown.

Fig. 285.—Ground section through the mandible where the bicuspid had been extracted.

An old dry mandible was sawed through in the positions indicated in the illustration (Figs. 282, 283, and 284).

The portion containing the bicuspid and molar on the left side was ground through the molar to obtain a section parallel with the axis of the tooth. The portion between the alveolus of the cuspid and second bicuspid on the left side was ground vertically through the area where the first bicuspid had been (Fig. 285). The portion on the right side containing the two bicuspids and molar was ground to give three sections at right angles to the roots—one in the gingival third, one about the middle of the root, and one just at their apices (Fig. 286). The distal portions of the bone were decalcified and sections cut through the alveoli of the second and third molars (Figs. 287 and 288).

[1] Journal of Morphology, 1888.

The Distribution of Bone in the Mandible.—In Chapter XVII, on Bone, it was stated that the arrangement of the layers in the tissue could be read as a record of the manner of formation. In the examination of these sections the arrangement of the lamellæ is to be

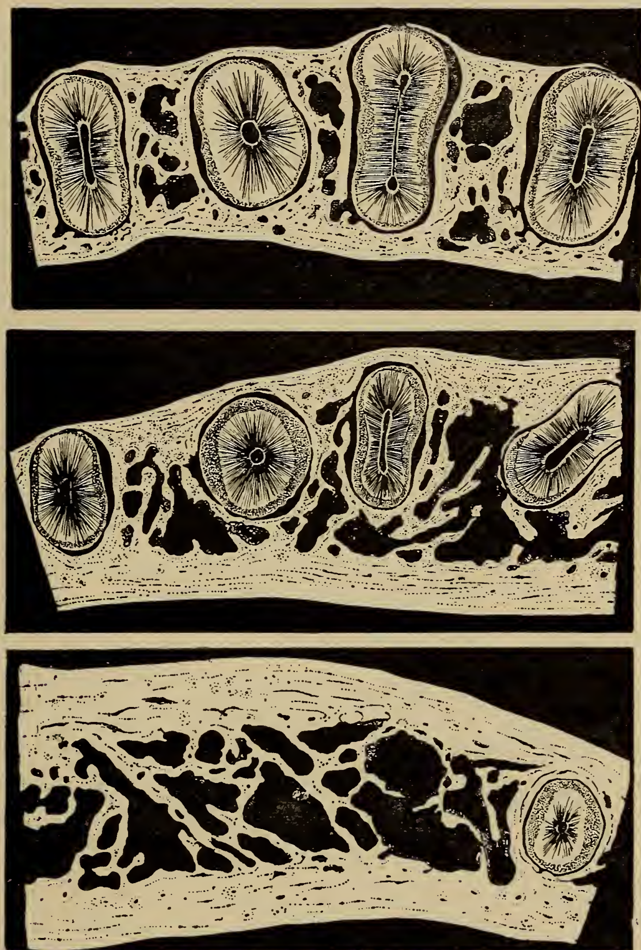


Fig. 286.—Transverse sections through the roots of two bicuspids and the first molar, showing distribution of bone.

studied in this way, as well as the distribution of the varieties of bone. Where the bicuspid had been extracted the alveolus has been filled with fairly compact bone, rounding over the border of the process. The section ground through this position shows the

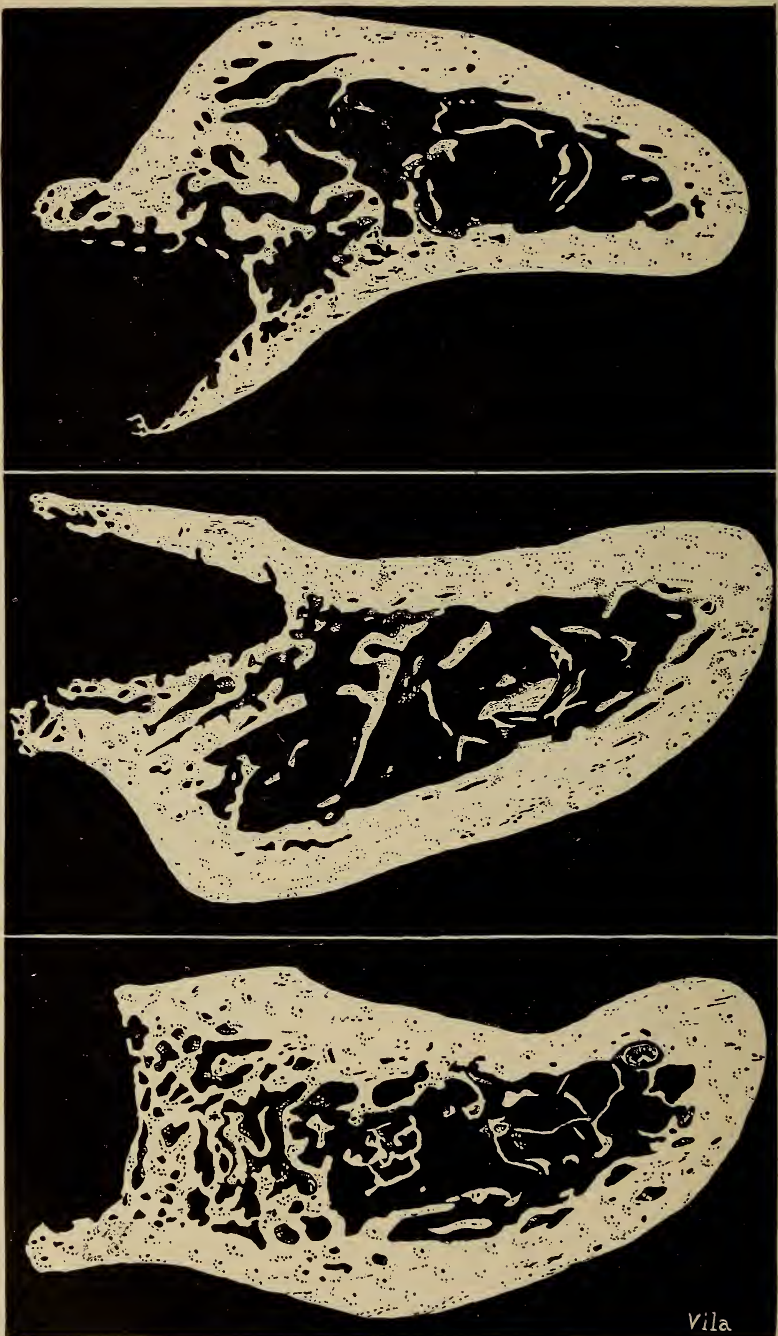


FIG. 287.—Decalcified sections through the molar region.

FIG. 288.—Decalcified sections through the alveoli of the second and third molars.

buccal and lingual cortical plates in U shape. The two plates are braced together across the central portion by spicules of cancellous bone. At the occlusal border the outline of the old alveolus can still be seen by studying the section carefully with the microscope. After the extraction of the tooth the socket was first filled with connective tissue, which was later transformed into bone, joining

Fig. 289.—A section ground through the first molar.

that of the alveolar wall. Near the lower border, the subperiosteal bone is found to be very thick, the bone evidently growing in that direction. Near the occlusal border on the lingual side, there have evidently been absorptions of the surface, removing the Haversian system bone, and then a few layers of subperiosteal bone have been reformed on the surface.

Fig. 289 shows a section ground through the molar. The cribriform plates lining the alveoli join the cortical plates at the border of the process. On the lingual side the wall of the process is very

Fig. 290.—The buccal plate from Fig. 286.

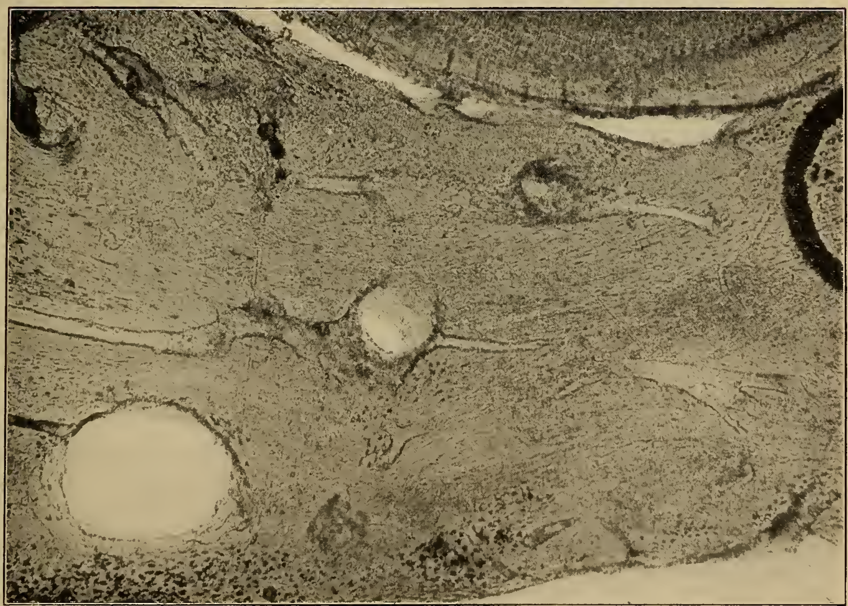


Fig. 291.—The lingual plate from Fig. 286.

thin, but is thickened in the occlusal third to support the tooth against force exerted lingually. On the buccal side the cribriform plate of the alveolar wall is connected with the cortical plate by spicules of cancellous bone. Below the apex of the root the cortical plates are connected by cancellous bone in which the medullary spaces are much larger. The same arrangement of the cortical plate and its bracing is shown in Fig. 287, which cuts between the alveoli of the second and third molar. Fig. 327 and Plate XIX should be studied in this connection, remembering that the bone has been formed and shaped by formation of subperiosteal bone on its surface and subperidental bone at the border of the process and their transformation into Haversian system and cancellous bone.

Fig. 286 is cut transversely. Notice that the gingival section has been turned over in mounting. Observe the cribriform plates forming the walls of the alveoli, and the way these are braced against each other and the cortical plates by bands of cancellous

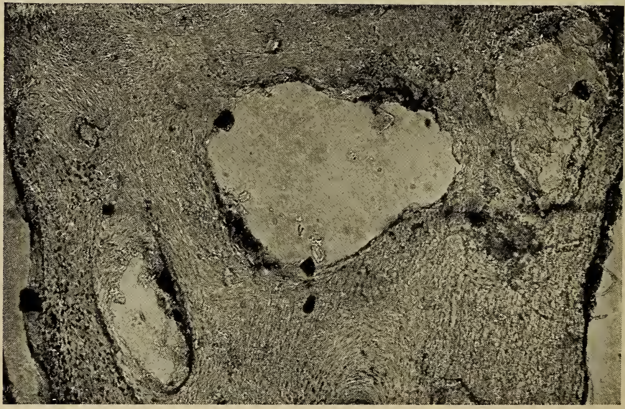


Fig. 292.—The bone between the alveoli of the mesial and distal roots of the first molar, from Fig. 286.

bone. In accordance with the principles noted, the buccal plate is thin and very compact, while the lingual plate is much thicker, but more open in structure, and the direction of growth has been toward the buccal as the arch of the jaw increased in size. Fig. 290 shows the buccal plate with higher magnifications, Fig. 291 the lingual plate, and Fig. 292 the bone separating the alveoli from the mesial and distal roots of the molar. The third figure of this series shows only the tip of the distal root of the molar, but the arrangement of plates of cancellous bone between the cortical plates is nicely shown.

The Maxilla.—In the maxilla the arrangement is exactly on the same plan, the details being different because of the difference in the shape of the bone.

THE GROWTH OF THE JAWS.

It has long been noted that at birth the mandible is straight, and with the eruption of the teeth the ramus develops and the body increases in size. In this process the thickness of the bone is increased from the mental foramina to the alveolar border, and the body of the bone approaches a right angle with the ramus. When the teeth are lost or lose their function the alveolar process is destroyed and the bone reduced in thickness from above downward until the mental foramen comes to lie on the upper surface of the bone. The mandible performs two functions, a respiratory and a masticatory function, and it should be remembered that these are influential in its development. The object of this section is to give some conception of the direction of growth in the devel-

Fig. 293.—Skull at birth.

opment of the bones of the face and the way in which the changes are brought about.

This can best be done by studying the series of skulls from childhood to old age, in which the outer cortical plate has been removed so as to show the developing teeth in their crypts and the relation of the forming teeth to those already in occlusion (Figs. 293 to 307). At birth all of the teeth except the second and third molars have begun to develop, and their tooth germs are lying embedded in the cancellous substance of the maxillæ. In the upper jaw they occupy almost all of the space to the floor of the nose and orbit, and there is little if any indication of the maxillary sinus (Fig. 293).

Each tooth germ is enclosed in a separate crypt, the wall of which is formed by a cribriform plate. The walls of the crypts are braced

Fig. 294.—Maxillæ at about eight months after birth, showing the unerupted tooth.

Fig. 295.—Maxillæ at about one year.

against each other and the cortical plates of the maxillæ by spicules of cancellous bone surrounding medullary spaces. As the tooth develops within its crypt, pressure is exerted and the crypt wall is pushed backward through the cancellous bone.

Growth Force.—The force exerted by the growing tooth is the result of the multiplication of cells in the tooth germ, and is exactly comparable to the forces exerted by multiplication of cells in any position. For instance, the force exerted by the multiplication of the cells in a rootlet of a plant is sufficient to force pebbles aside and make an opening through hard packed earth. Some attempts have been made to measure the amount of force, but we can only say that it appears to be considerable, acting through short range.

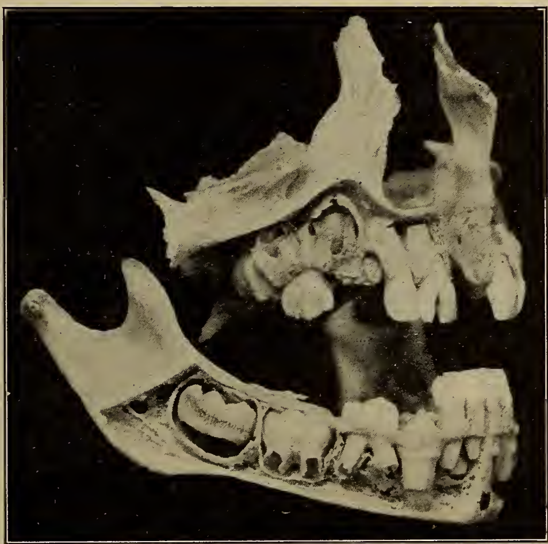


Fig. 296.—Maxillæ at one and one-half years.

How this force is generated has been a matter of much speculation and investigation. It shows some points of similarity with the swelling of wood fibers when water is added. It apparently is related to osmosis, and has some direct relations to blood-pressure. It is certainly a very complicated matter, with chemical affinities at the bottom of it.

Forces Influencing Bone Growth.—While the growing tooth germs are producing force which causes conditions of stress of the cortical plates, the growth of the tissues within the mouth—the tongue and the associated organs—is exerting pressure upon the lingual surfaces of the bone. The muscles attached to their surfaces transmit force to the bone through the periosteum, and the functions of mastication, deglutition, and respiration are acting upon them. All of these are mechanical stimuli, to which the connective-tissue cells respond. In all the process of development the growth is the result of all the forces to which the bones are subjected, perfectly distributed through the substance of the bone by the agency of normal occlusion. Any lack of harmony in the proportion of

Fig. 297.—Maxillæ in the second year, showing the relation of the erupting teeth. Note the relation of the crypt of the second molar to the inferior dental canal.

these forces may allow the teeth to meet, when they erupt, outside of the normal influence of their cusps, causing the beginning of malocclusion. Any malocclusion disturbs the balance in the distribution of forces, and results in a disturbance of the development of bone, which progresses during the entire period of development. This must result in the lack of balance in the proportions of the features which will be proportionate to the malocclusion.

It has been natural and almost inevitable, because of their hard-

Fig. 298.—The complete temporary dentition (about three years), showing the relation of the developing permanent teeth.

Fig. 299.—The complete temporary dentition and the first permanent molar. Note the relation of the bicuspids to the temporary molars. (In the seventh year.)

ness, to think of bones as solid and unchanging. In the study of these skulls the bones of the face must be viewed not as solid and rigid, but as containing millions of active cells which are continually building and rebuilding their substance.

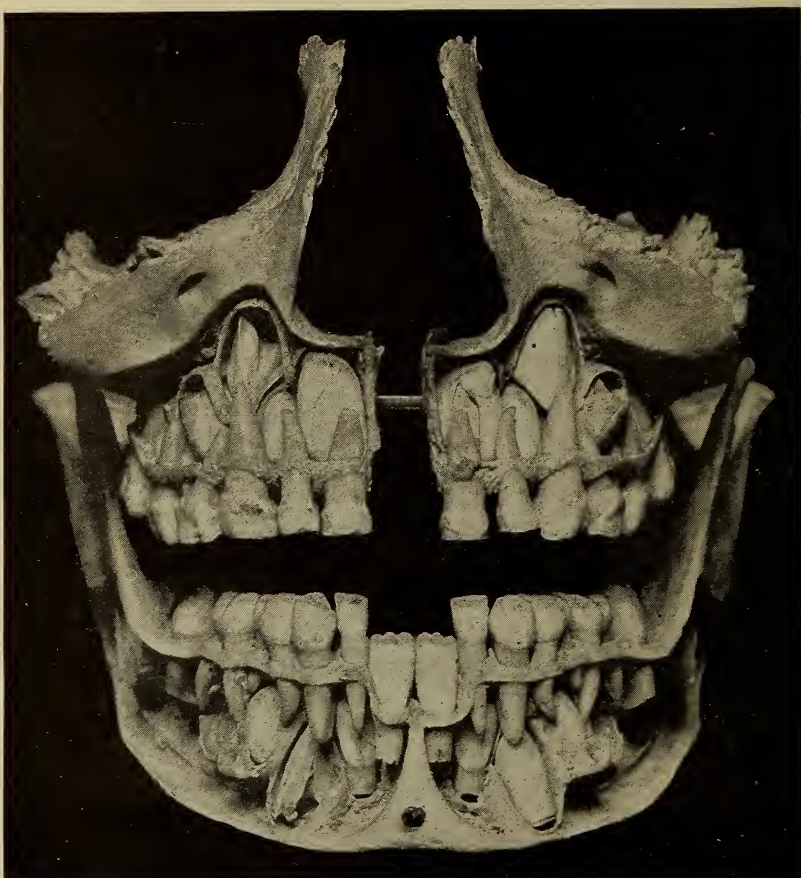


Fig. 300.—Front view of the skull shown in Fig. 299. Note the relation of the permanent incisors and cuspids to each other and the roots of the temporary teeth.

Usually somewhere between the seventh and ninth months after birth the growth of the central incisors causes the absorption of the roof of their crypts, and the tooth moves occlusally, cutting through the soft tissues (Fig. 294). The formation of cementum on the surface of the root and of bone on the wall of the crypt attach the connective-tissue fibers and form the beginning of the peridental membrane. As the tooth moves occlusally the bone grows up around it from the circumference of the crypt wall, converting it into the wall of the alveolus. The root is not fully formed and the conical pulp filling the funnel-like end exerts force by the

Fig. 301.—Dentition in the eighth year. Note the position of the cuspids and compare with Fig. 303.

multiplication of cells and the blood-pressure, which cause the tooth to move occlusally and the bone to grow in that direction. At the same time the pressure of tongue and lips exerts pressure on the surfaces of the tooth and bone, influencing the direction of bone growth. The jaw increases in thickness in the occlusal direction and grows forward and outward. At the same time the growth of each successively distal tooth is exerting pressure upon those already erupted, causing them to move farther in the occlusal direction. In Figs. 296 and 297 notice the way in which the crypt walls are pushed downward by the development of the tooth root

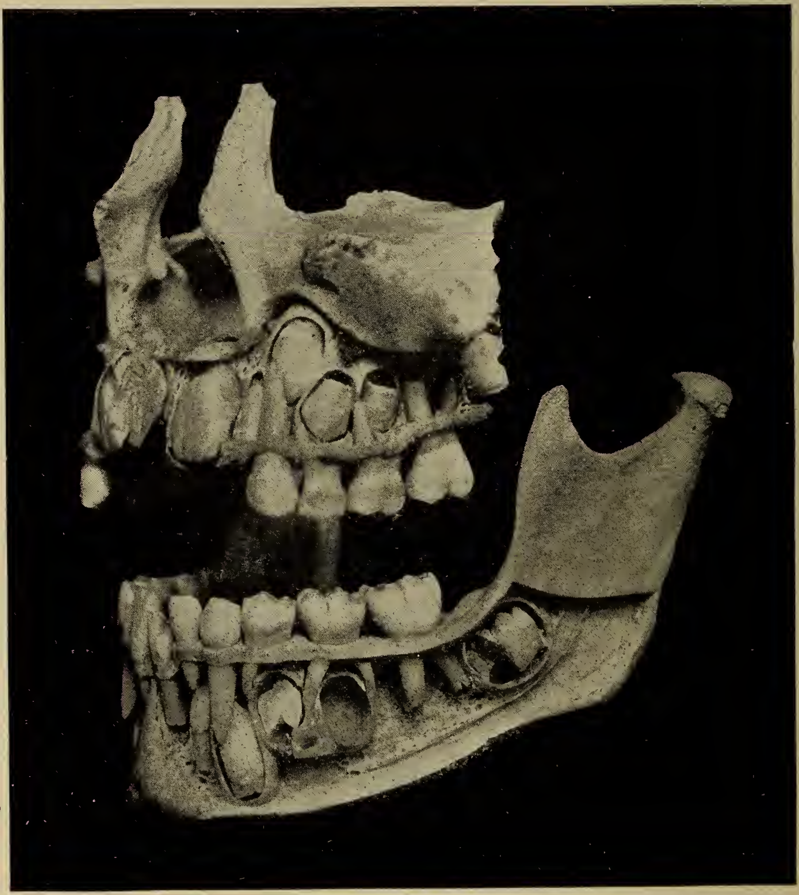


Fig. 302.—The left side of the skull, shown in Fig. 301.

until the inferior dental nerve lies between the floor of the crypt and the cortical plate of the lower border. In this way enough pressure may be produced to cause reflex nervous symptoms, which commonly precede the eruption of the temporary molars, and so development continues until all of the temporary teeth are in place. About the sixth year the first permanent molars take their place at the distal of the temporary teeth and their cusps interlock (Fig. 299). The importance of these teeth can scarcely be overstated. They are not only to be the chief means of mastication

FIG. 303.—Dentition in the eleventh year. Note the growth of the cuspids and bicuspids. The second molar is about to erupt.

during the period in which the temporary teeth are lost and replaced by their successors, but they are to maintain the relation of the jaws to each other. The way in which these teeth lock determines the balance between the forces exerted by the action of the muscles attached in the region of the ramus, and those in the region of the symphysis (Fig. 299).

A deviation from the normal relation of these teeth will entirely change the direction of the forces, and will be manifested by a modification in the development in the bone. In the skull at this period the bicuspids are seen lying below the temporary molars, and the second molar developing at the distal of the first. Their

Fig. 304.—Dentition in the thirteenth year. Note the relation of the bicuspid crown to the roots of the lower temporary molar.

growth is transmitted through the teeth to the alveolar process, and the addition of bone results. The same skull viewed from in front (Fig. 300) shows the relation of the permanent incisors and cuspids to the temporary ones. In the lower jaw the temporary centrals have been lost and the permanent ones are forcing their way between the temporary laterals. The crowns of the centrals are wider than those of the teeth that were lost, and they consequently exert pressure upon the mesial surfaces of the laterals, pushing them apart and carrying them upward and forward.

Study the relation of the lower centrals, laterals, and cuspids in the development of the arches at from six to ten years. Notice that the roots of the central are not fully formed, that the lateral

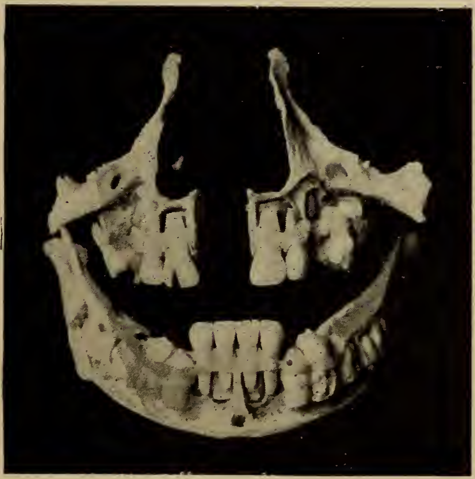
Fig. 305.—The dentition of a young adult. The third molars have not erupted. (About fifteen years.)

lies to the lingual of the temporary lateral root, and with its mesio-occlusal angle below the distal surface of the central. The development of the cuspid has pushed the crypt floor through the cancellous bone until it has reached the solid cortical plate, and still the formation of the crown is not quite completed. The six teeth form a

Fig. 306.—Adult dentition. Note the distance from the apices of the incisors to the lower border of the mandible and the floor of the nose.

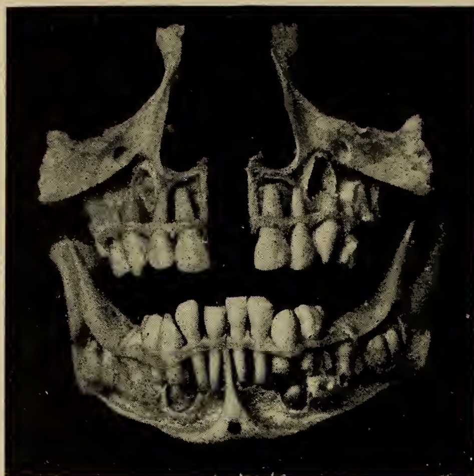
Fig. 307.—Edentulous jaws, showing loss of alveolar process.

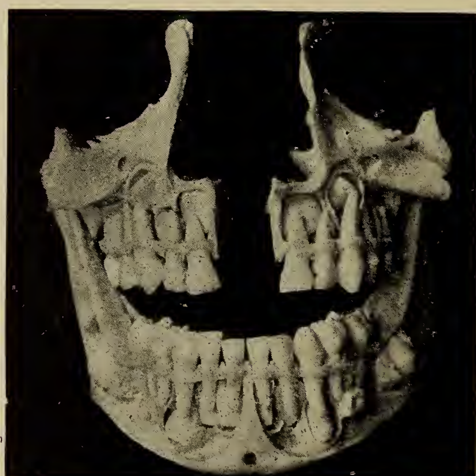
triangle of which the centrals are the apex, and the cortical plates from cuspid to cuspid the base. The completion of the roots of



Figs. 308 and 309 were photographed in the same relative size, to show the amount and direction of growth, with the development of the full permanent dentition.

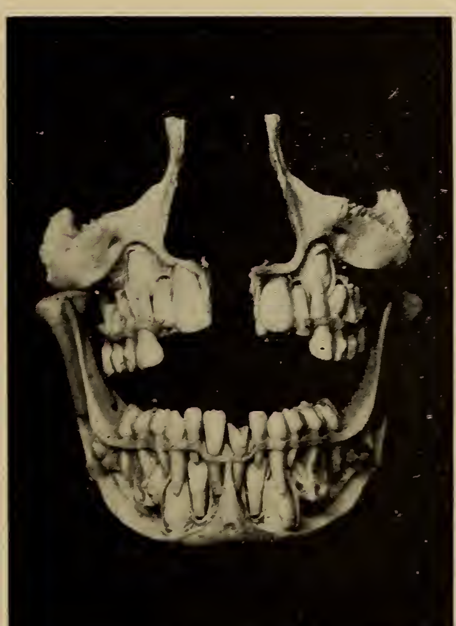
these teeth will carry the temporary teeth, alveolar process and all, upward, forward, and outward, thus increasing the distance from the mental foramen to the symphysis and enlarging the arc of the jaw from cuspid to cuspid.



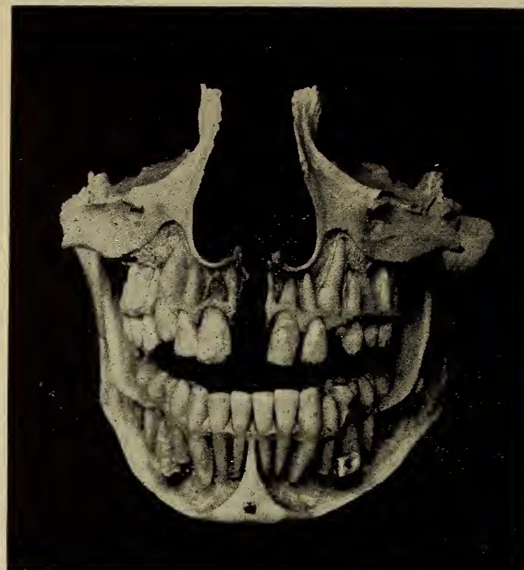


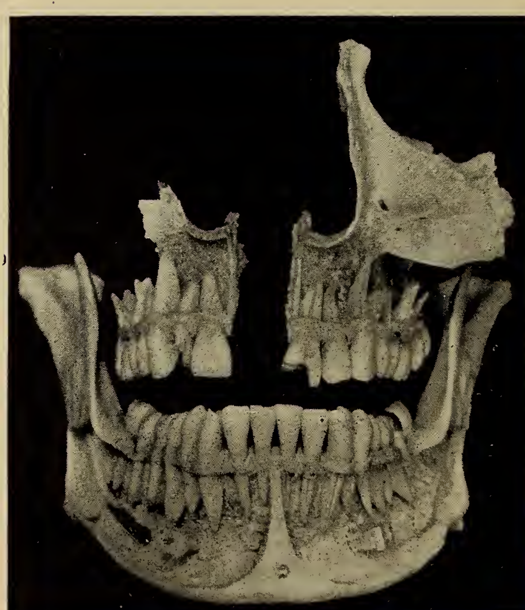
Figs. 310 and 311 were photographed in the same relative size, to show the amount and direction of growth, with the development of the full permanent dentition.

In the same skull notice the relation of the upper incisors and cuspids to the corresponding temporary teeth. They lie to the lingual of the roots of the temporary teeth, the lateral a little to



FIGS. 312 and 313 were photographed in the same relative size, to show the amount and direction of growth, with the development of the full permanent dentition.





Figs. 314 and 315 were photographed in the same relative size, to show the amount and direction of growth, with the development of the full permanent dentition.

the lingual of the central and cuspid. The cuspid has pushed back the floor of its crypt until it is braced against the solid bone at the base of the malar process. The growth of these teeth will first cause the temporary teeth to move occlusally, the bone growing from the border of the process to follow them. In this growth the distance from cuspid to cuspid is increased and spaces appear between the temporary incisors some time before they are lost.

If such spaces do not appear, the development is not progressing normally, and artificial force should be applied to stimulate bone growth. If this is not done the permanent teeth are sure to come in more or less rotated and out of position.

In Figs. 301 and 302 the incisors have been pushed off and the permanent ones are beginning to move occlusally. Notice the relation of the floor of the crypt to the floor of the nose, and the root has scarcely begun to develop. In the adult skull (Fig. 306) there is almost as much space from the apex of the root to the floor of the nose as there is now from the border of the alveolar process to the floor of the nose. The result of the growth of the cuspids' roots is shown by comparing Figs. 300 and 301 with Fig. 303.

The Importance of Proximal Contact.—The proper contact of the teeth upon their proximal surfaces is necessary for this development. If, for instance, the mesial angle of the lower lateral fails to engage with the distal surface of the central, but slips by to the lingual, the growth of the cuspid will push it farther and farther past the central instead of enlarging the arch. One of the cogs in the mechanism has slipped, and the growth of bone cannot later be expected to make room for the crowded teeth.

In the next stage of growth the increase in size is from the mental foramen to the ramus, and is largely influenced by the development of the roots of the bicuspids and the second molars. Figs. 302 and 303 show the relation of the second molar to the distal surface of the first, and it will be seen that its growth exerts force upon the first molar, and this is transmitted through the arch by means of proximal contact. Notice the inclination of the bicuspid roots, which help to carry the growth in the same direction.

After the second molar is in place the growth of the third should exert the same force and room be provided for it (Fig. 304). The muscular action of the lips and tongue are specially important in these last stages of growth, and particularly the forces that are generated by the action of the muscles in respiration and deglutition. The activity of the connective-tissue cells in the bone requires mechanical stimuli for their maintenance, and as the muscular action is vigorous or deficient, the growth of bone will be full and normal or imperfect and unbalanced. It appears often that the bone activity becomes so sluggish that the growth of the third molar cannot produce the effect it should, and it remains impacted. A comparison of figures will show that while room has been made for the third molar, all of the upper teeth have moved downward, forward, and outward, and the lower ones upward, forward, and outward. Compare the distance from the apex of the incisor

Fig. 316.—Two years.

Fig. 317.—Three years.

Fig. 318.—Six years.

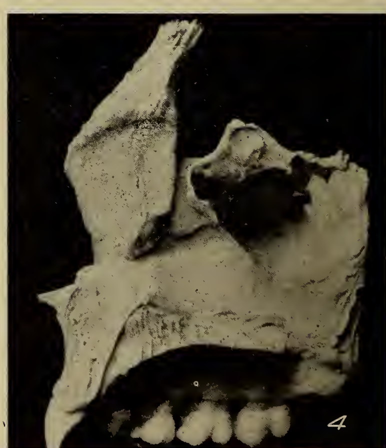


Fig. 319.—Ten years.

Maxillæ photographed from the median line in the same relative size, to show the amount and direction of growth.

Fig. 320.—Twelve years.

Fig. 321.—Adult.

Maxillæ photographed from the median line in the same relative size, to show the amount and direction of growth.

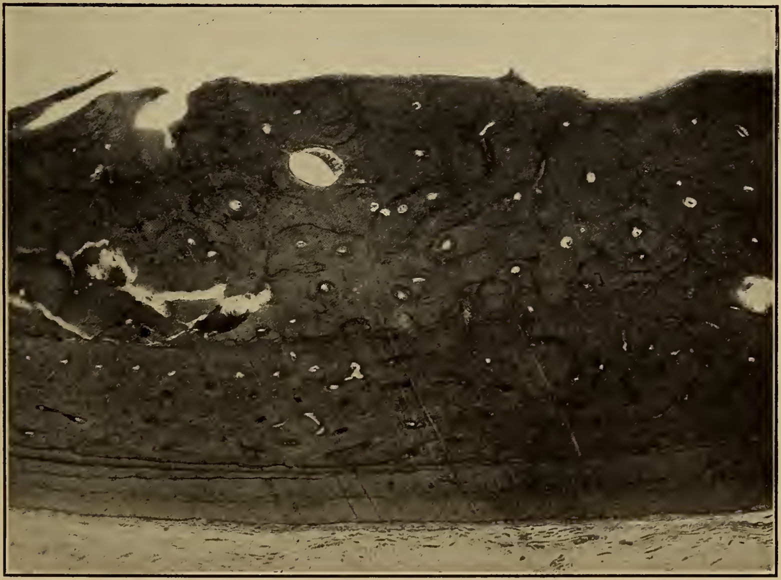


Fig. 322.—Bone from the buccal plate of the mandible of a young sheep, showing transformations of bone: *1*, subperiosteal bone; *2*, Haversian system bone; *3*, Haversian system bone becoming cancellous.

roots to the floor of the nose and the lower border of the mandible in Figs. 305 and 306.

FIG. 323.—The record in the arrangement of the lamellæ of the growth of the mandibles. A decalcified section from near the lower border of a human mandible.

This process may be more fully realized by comparing the front views of the skulls (Figs. 308 to 315). They were all photographed with the same lens and bellows length, so as to make the pictures of the same relative size as the skulls. Notice the increase in distance from the floor of the nose and the floor of the orbit to the edges of the upper incisors, and from the lower border of the mandible to the edge of the lower incisors. It will be seen that if the infant mandible were placed in relation to the adult mandible it would lie entirely within the arch and in the mouth cavity, while

Fig. 324.—A decalcified section from the lingual vertical plate of a human mandible, showing the arrangement of lamellæ as a record of growth.

in the upper the temporary incisors in Fig. 315 would be some place in the nasal cavity. In all of this growth the size of the air spaces increases with the movements of the teeth, the floor of the nose and palate growing downward and developing. This may be shown in Figs. 316 to 321, in which the right half of the maxilla has been removed from dissected skulls and photographed from the median line.

Tissue Changes in the Physiologic Movements of the Teeth.—All that has been said in regard to bone growth must be recalled in

Fig. 325.—Cancellous bone from a decalcified section of a human mandible, showing reconstructions to change the direction of the spicules.

order to obtain a conception of the manner in which these movements of the teeth and the development of the bone are accomplished. Bone laid down under the periosteum and the peridental membrane has been transformed into Haversian system bone and then made cancellous, as illustrated in Fig. 322, which is taken

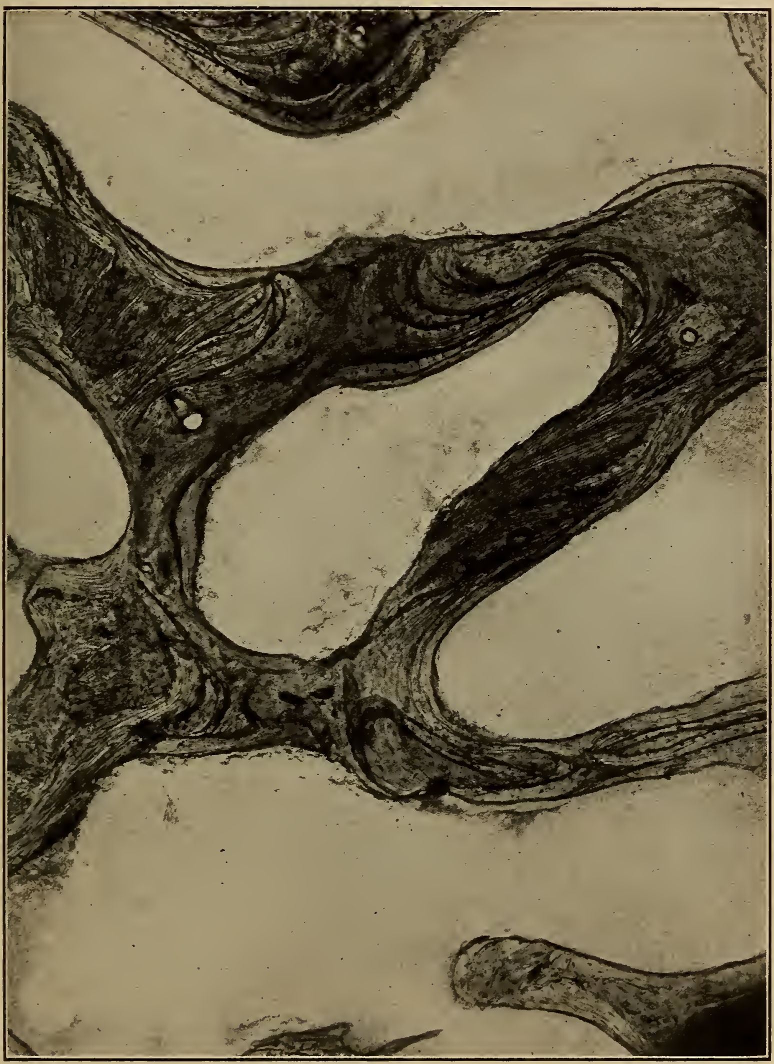


Fig. 326.—Decalcified section of cancellous bone from a human mandible, showing absorptions and rebuildings, changing the direction of the spicules.

from the buccal plate of the mandible of a young sheep. Reversed changes have also been going on, the periosteum cutting into the

Haversian bone by absorption and the cancellous bone being condensed into Haversian system bone. These changes leave a record in the arrangement of the lamellæ, and may be studied in decalcified sections (Figs. 323 to 326). Even the direction of the spicules of

Fig. 327.—A longitudinal section through the tip of the alveolar process of a temporary tooth about ready to be lost: *D*, dentin; *Cm*, cementum, showing absorption and rebuilding; *Pd*, peridental membrane; *B*, bone growing occlusally at the border of the process; *Hb*, rebuilt Haversian system bone.

cancellous bone are being constantly changed by absorptions and rebuilding to adjust them to changes of stress.

While the temporary teeth are moving occlusally, bone is laid down under the peridental membrane at the border of the alveolar process, which is at once cut out by absorptions and replaced by

Haversian system bone (Fig. 213). The alveolar process becomes a veritable patchwork, as shown in Figs. 327 and 328. The

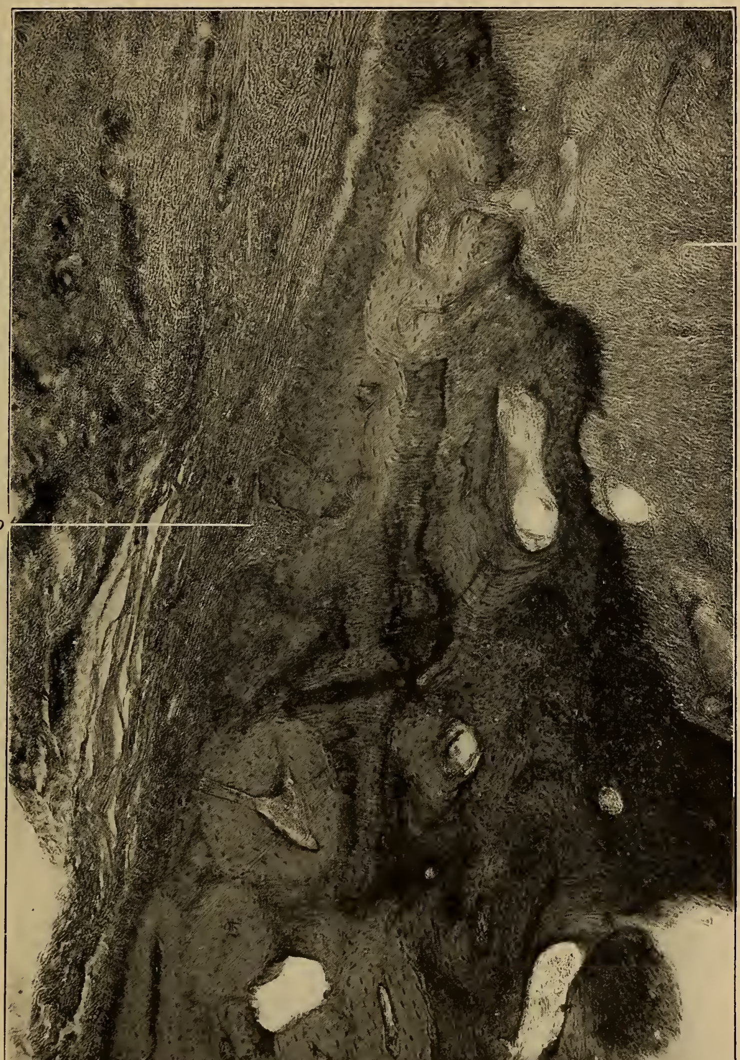


Fig. 328.—A longitudinal section through the temporary alveolar process, which is growing occlusally to follow the temporary tooth. It is from the same series as Fig. 327, but shows more of the bone. Study the absorptions and rebuildings, as shown in the arrangement and character of the lamellæ. *Pd*, peridental membrane; *Po*, periosteum.

permanent tooth developing in its crypt produces conditions of pressure, and osteoclasts appear in all the medullary spaces, around

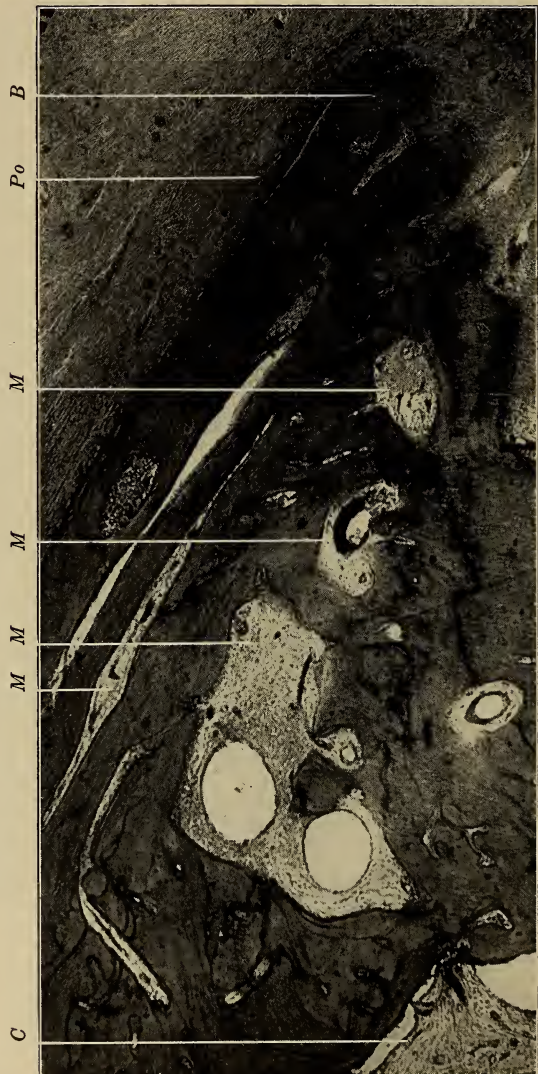


Fig. 329.—A longitudinal section of the alveolar process about a temporary tooth, including the bone of the crypt of the permanent tooth. Notice the enlargement of the medullary space preparatory to the eruption of the permanent tooth: *B*, bone at the border of the process; *Po*, periosteum; *M*, medullary spaces, showing enlargement; *C*, crypt of permanent tooth.

and above the crypt, and through the alveolar process, as well as on the crypt wall. They are more active in the medullary spaces, cutting away the spicules of bone, thinning and cutting apart the crypt wall, and allowing it to be bent and pushed back.

Fig. 330.—A section through the labial plate of the alveolar process about a temporary tooth, which is moving upward, forward and outward, under the influence of the developing permanent teeth. Note that bone formation is going on on the whole of the labial surface under the periosteum, and that both formation and destruction are going on on the peridental membrane side, but that destruction is in excess.

Fig. 329 shows the alveolar process on the lingual side of the temporary incisor, and illustrates the enlargement of the medullary spaces preparatory to the eruption of the permanent tooth. Fig.

330 shows the labial plate of the process, and notice that the bone is being formed under the periosteum and at spots under the peridental membrane, while the substance of the bone is being destroyed.

Fig. 331.—A longitudinal section through the alveolar process just after the eruption of the permanent tooth. Addition of bone for the attachment of the permanent tooth is just beginning on the remnants of the temporary alveolar process: *B*, newly formed bone. (The picture was made by photographing the fields and joining the prints.)

When the tooth is finally pushed off from the gum all but a few bits of the alveolar process have been destroyed, and as the permanent tooth comes through, bone formation begins at the border, patching on to the remains of the old process (Fig. 331).

In studying the absorption of bone around the crypt walls, it has been noted that the osteoclasts appear first in the cancellous bone (Figs. 214 and 215), surrounding the crypts and outside of it. Absorptions here remove the spicules which brace the crypt wall, and cut through the wall in such a way as to allow it to be pushed back through the weakened substance. In the same way in the movements of the teeth, absorptions appear first in the spaces outside of the cribriform plates of the alveoli, until the remaining bone is weakened sufficiently to spring under the pressure. All of the sections of the mandible should be studied as a record of these bone transformations, and especially in orthodontia it should be remembered that appliances are used not to push the teeth through the bone as a post would be pushed through the mud, but to supply mechanical stimuli to living cells whose activity will result in bone growth, carrying the teeth into their proper positions, *and finally, that teeth will remain only in the position in which all of the forces to which it is subjected are balanced.*

PART II.

DIRECTIONS FOR LABORATORY WORK.

(TWENTY-FIVE PERIODS IN THE LABORATORY.)

PRELIMINARY.

It is assumed in this work that the student has had a course in general histology, including laboratory work, that he is familiar with the technique of handling the microscope, the technique of staining and mounting sections, and that he is able to recognize at once the elementary tissues. The same outfit is required as for general histology, including slides and blank labels for them; cover-glasses; teasing needles; forceps; section lifter; a tube of balsam; a funnel; pipette; filter paper and lens paper; 6 one-ounce reagent bottles containing xylol, absolute, 95, and 70 per cent. alcohols, hematoxylin, and eosin; at least two chip butter dishes that can be used for staining; a box for the slides; a note-book; a hard and a soft drawing pencil; a good eraser; and a piece of clean soft linen for wiping slides and cover-glasses.

Teeth for Grinding.—It is difficult to obtain satisfactory teeth for the grinding of microscopic sections, and the student should bring to the laboratory a number of suitable teeth from which selection can be made. Old, dry teeth are absolutely useless for the purpose, however perfect their structure may have been. When a tooth has been extracted for some time the tissues dry out, giving up a considerable amount of water, and consequently shrink. The shrinkage of dentin and enamel is unequal, and the result is a cracking of the tissue. The observation of the teeth in any skull will reveal cracks in the enamel that may be seen with the naked eye, the tooth often splitting lengthwise. Besides the cracks that can be seen, the tissue is full of microscopic cracks. When the grinding of sections from such teeth is attempted, before the section is reduced to sufficient thinness for microscopic observation the enamel will break to pieces and be lost. A tooth that is to be used for grinding must be placed in solution as soon as it is extracted, *and never at any stage of the process be allowed to dry,* until ready for mounting. Any solution that will prevent decomposition will do for this purpose. The best that I have found is a 4 per cent. formaldehyde in 50 per cent. alcohol. This may be roughly prepared by diluting 95 per cent. alcohol with an equal volume of water and adding one part of formalin to nine parts of the diluted alcohol:

Alcohol	45 c.c.
Water	45 c.c.
Formalin	9 c.c.

This solution not only prevents the drying, but has a hardening action on the organic matter, which facilitates the grinding. Teeth may be preserved in this indefinitely.

Teeth Required.—From his collection the student should select for grinding an incisor or cuspid, a bicuspid, and a molar. The teeth should be free from caries and their crowns as perfect as possible.

The Relation of the Section to the Crown.—The practical value of the study of ground sections depends upon obtaining from them a knowledge of enamel-rod directions in relation to the tooth crown as well as the section. In operating the teeth are looked at from their outside surface, but the operator needs to see in the enamel not simply a hard and extremely dense tissue, but a tissue made up of minute rods whose general direction he knows beforehand. If a tooth is selected and a section cut from it in a known position, and the relation of the section to the crown remembered, the direction of enamel rods can be placed in relation to the entire crown as well as to the section. This is one of the objects to be sought in the making of the outline drawings.

Location of the Section.—Having selected the teeth for grinding, the next step is to locate the position and direction of the section. This must be so placed as to cut the enamel rods in their length. The section from the incisor or cuspid should be ground labiolingually, but the section from the molar and bicuspid may be ground either buccolingually, mesiodistally, or diagonally. The surface of the tooth should be considered, and the section placed in an area in which the student desires to discover the enamel-rod directions and the structure of the tissue. The line of the section should now be marked on the tooth with India ink and a fine pen.

The Drawings of the Teeth.—After marking the position of the section the tooth should be carefully and accurately drawn, showing the position of the section as seen from the axial and occlusal surfaces.

Grinding of the Section.—Every institution should have a machine for the preparation of ground sections, but such a machine is too delicate an instrument to be handled by students. In the appendix will be found a chapter written by Dr. Black describing the grinding machine and the technique of its use. If one is available, the student may have his sections ground for him and returned ready to mount, or he may grind them himself, using the following technique:

Preparation of Ground Sections of the Teeth.—For this work the student should have two large corundum stones not less than four inches in diameter, one of "C" and one of "E" grit. Corundum is very much better than carborundum for this purpose. In grinding the stone should be kept revolving slowly and moistened with a stream of water. Holding the tooth against the flat side of the coarse stone with the fingers, the tissues should be rapidly ground away until the position marked for the section is reached, when the fine stone should be substituted and the grinding continued just enough to remove the scratches. The surface should now be polished on the Arkansas stone until a very perfect surface has been obtained. Wash the specimen clean and immerse in several changes of 95 per cent. alcohol, and leave in absolute alcohol in a closed bottle for several hours or over night. Harden a drop of balsam on the center of a clean slide by warming it over a Bunsen burner to evaporate the xylol. When the slide is cool the balsam should be neither sticky nor brittle. Now remove the tooth from the alcohol, wipe it dry, and, placing it on the balsam with the polished surface next to the glass, gently warm the slide until the balsam is thoroughly softened, and press the tooth down against the glass and clamp it firmly in position, using a spring clip. Set it away to harden thoroughly, when the grinding may be continued.

Holding the slide parallel with the surface of the coarse stone, the tissues may be rapidly removed until the section is about as thin as a calling card, when the fine stone should be substituted and the section reduced to the required thinness. It should not be more than twenty microns in thickness. In the final stages progress of the grinding may be followed with a hand magnifying glass. Finally the surface should be polished on an Arkansas stone. The specimen should now be washed with alcohol, the balsam removed with xylol, and brought to the laboratory in 95 per cent. alcohol, where it is to be etched and mounted according to the directions.

Every step in the above technique is important and must be followed with minute care and accuracy. Not least important is the cleaning of the slide. It sometimes happens that the section will be loosened from the glass before the grinding is completed. This is usually due to some fault in the technique. When it happens it is best to finish the grinding without attempting to refasten the section to the slide. To do this the section should be held against the flat side of the stone, using a fine-grained cork, a piece of boxwood, or some similar material. The danger of breaking the section, however, is much greater.

The Preparation of Transverse Sections of the Root.—For this purpose one of the flattened roots furnishes the best material, as, for instance, the mesial root of a lower molar, the root of a lower bicuspid, or of an upper second bicuspid. Holding the root in a vise by the remains of the crown, with a metal saw, saw off the tip of the root, removing an eighth of an inch or less. Then saw off as thin a slice as possible. In the same way saw out at least two other sections, one from the gingival and one from the middle third of the root. These should be dropped into a bottle of formalin-alcohol until the grinding is completed. The grinding is easily accomplished on the flat side of the corundum stone, holding the section on the finger or under a cork. The last grinding should be done on the fine Arkansas stone.

Transverse sections of the root are easily ground and can be made very thin.

Manner of Working in the Laboratory.—In no place in the world can time be wasted more easily than in the histological laboratory. The student should take the attitude of an original investigator and study out the material for himself as far as possible, remembering that he has a far better opportunity than the man who worked out the details of these structures. He must constantly try to picture the structure, and imagine how it would appear if sectioned in another direction.

Drawings.—Drawings from the microscope are made not simply to occupy the student's time, nor as a record of what he has done, but to make observation more accurate and detailed, and to fix the impressions of structure more perfectly in mind. Many students excuse themselves for careless and slovenly work by saying that they are not artists. Anyone without any knowledge of the principles of art can in a very short time acquire the ability to make excellent microscopic drawings. A few principles of procedure will help greatly. The first of all is that a light line can always be made darker, therefore the drawing should always be kept light until the later stages.

After selecting a field, draw lightly the outline of the principal masses and then the outlines of the smaller ones. In this way the proportion of objects in the field and their relation to each other can be maintained. Never draw any detail such as individual cells, nuclei, etc., until all of the outlines are completed. Then work in the details in the darker colored areas. The making of the outlines is by far the most important stage in the drawings.

Each outfit should contain a 6 H and an H-B pencil and a good eraser, which must be kept clean. The pencils should be kept sharp and always used with a light touch upon the paper. The beginner always tends to start his drawing by making a circle. This should be avoided, for it is objects that are being studied, not fields, and in many cases the object cannot be bounded by a circle. There is also a tendency to represent the object smaller on the paper than it appears in the field.

The prime qualities in a microscopic drawing are *accuracy* and *correctness of detail.* The drawings are made to show all the detail of structure that can be observed. It often happens that a drawing that looks very well shows very little knowledge of the structure of the tissue which it represents.

Stencilled Laboratory Notes.—In fifteen years of teaching the author has found stencilled notes on the daily work in the laboratory of very great assistance. There are always variations in the appearance of the material which cannot be anticipated before the sections are cut. Very often something will be seen unusually well that would not be mentioned in the text-book. Different stains may have been used which would change the appearance of the tissues, and for all of these things and many others daily notes are very convenient.

USE OF DIRECTIONS FOR LABORATORY WORK.

At the beginning of the laboratory period the first thing to be done is to read *through the directions for the day's work.* The amount of work for the day is then clearly in mind, and all the steps in any procedure that is to be undertaken are understood at the beginning. It is necessary to divide the time available, so as to accomplish the work indicated for the day.

PERIOD I.

Drawings of Tooth Surfaces Showing the Position of Sections.—The object of these drawings is to show the relation of the section to the crown from which it is ground, so that in studying the enamel-rod directions as seen in the sections, they may be referred to the entire crown. The drawings should be made from five to ten times natural size, and must be made accurately to scale (Fig. 332). Measure the length and the breadth of the tooth and lay out a rectangle, say eight times these dimensions, to serve as a guide in drawing. If the tooth is marked for a buccolingual section, stick the apex of the root on a bit of wax and place the tooth on the table with the buccal surface toward you. *Do not change its position until the drawing is completed,* for to do so would change lights and shadows. After getting the outline accurately, work in the shadows so as to give the drawing roundness. Remember in doing this that you can always make it darker, but you cannot erase without injuring the neatness of the drawing. When the drawings are completed the section is ready for grinding, which must be done outside of the laboratory, following the directions in Introduction to Part II.

PERIOD II.

Etching and Mounting of Ground Sections.—At the desk will be found 1 per cent. hydrochloric acid, dilute ammonia, and vaseline, which are the only reagents not included in the outfit and required for this work. The sections are brought to the laboratory ground and ready to mount. Fill one of the dishes with water and carefully wash the specimen free from all debris of grinding. Dry the section between filter papers, so as to remove all moisture from the surface. Fill one dish with 1 per cent. hydrochloric acid, and the other with dilute ammonia. Put a very little vaseline upon the tip of the finger, and holding the section by the root portion, cover one surface of the crown portion with a very thin layer of it. In doing this the vaseline should be wiped from the center toward the edges of the section, so as to prevent it from running over on to the other surface. The vaseline is to confine the action of the acid to one surface of the enamel. Holding the section by the root portion, immerse the crown in the dilute acid for thirty seconds,

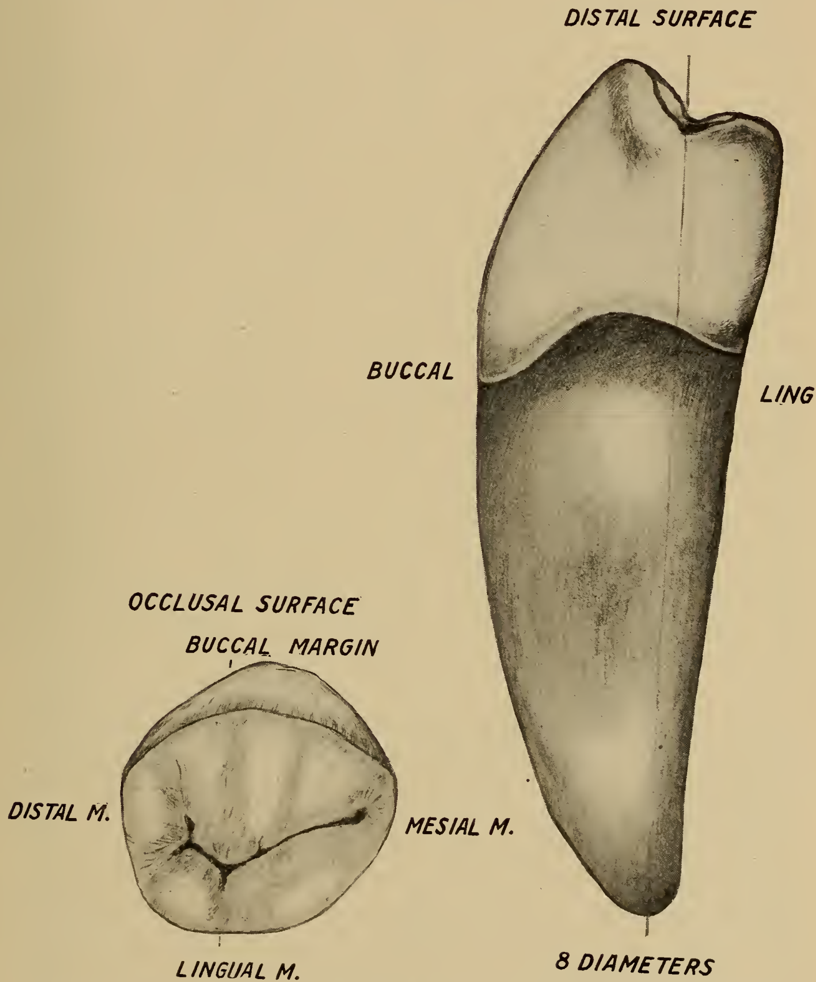


FIG. 332.—Drawing of occlusal and axial surfaces of a tooth to show the relation of the section to the tooth. (Drawn by W. A. Offil, 1910.)

or until minute bubbles can be seen forming upon the surface. Remove and immerse at once in the dilute ammonia for a minute. Remove the vaseline by carefully wiping the section with absolute alcohol or ether, and immerse in 95 per cent. alcohol. In this it should remain while the slide and cover-glass are being prepared. Obtain from the desk a cover-glass long enough to cover the entire section and carefully clean both slide and cover-glass. On the center of the slide place a drop of balsam that is as long as the section. Holding the slide over a Bunsen burner or alcohol flame, warm it gently so as to evaporate the xylol. In this process the drop will spread out over the slide and the direction of spreading may be guided by the heat. Allow the slide to cool and test the hardness of the balsam with a teasing needle or the finger-nail. When cold the balsam should be just soft enough to take the imprint of the needle or nail, but not be sticky. If it is sticky it must be reheated; if, on the other hand, it is brittle enough to chip, it must be scraped off from the slide and the process tried again. In the same way prepare a film of balsam on the cover-glass. Remove the section from the 95 per cent. alcohol and dry it for a few minutes in the air (after wiping with filter paper). Place the section, *etched side up*, upon the balsam on the slide, and place the cover-glass on it, *balsam side down*. Warm the slide gently over the flame, while pressing the cover-glass down with the handle of a teasing needle. As the balsam is warmed, the slide and cover-glass are brought together, forcing the balsam out to the edge of the cover-glass in all directions. All excessive balsam should be squeezed out at the edges. Place on the cover-glass a small piece of blotting paper or a layer of cork, adjust some sort of a spring clip and put the section away until the balsam is entirely hard. When the balsam is entirely hard the excess may be removed by gently scraping with a knife-blade and wiping with xylol. The section should now be labelled with the name of the tooth, the direction and position of the section, the student's name and number, and the date.

The mounting in hard balsam greatly improves the value of the section, for the dentinal tubules and the lacunæ of the cementum are left filled with air and can be more easily studied. Sections may, however, be mounted in the ordinary way, in soft balsam. If the section is broken or extremely thin, soft balsam should be used.

PERIOD III.

Outline Drawings from Ground Sections.—The object of the outline drawing is the study of the dental tissues, their distribution, portion of the tooth formed by each, their relation to each other, and the coarser points of their structure. To get the value from this work the drawings must be made very accurately to scale and as large as the note-book page will allow. With the Boley gauge or a millimeter rule measure accurately the length of the section, multiply this by eight or ten, and mark the length on a page of the drawing book. Measure the width of the section at the point of the greatest diameter and multiply this by the same factor. Using this for the width and the previous measurement for the length, lightly draw a rectangle, which is to be used as a guide in the construction of the drawing. The success of the drawing now depends on the accuracy and number of the measurements.

First measure the vertical distance from the incisal edge to the gingival line on one side of the section, and then on the other, and mark these on the sides of the rectangle. This will give the relative length of root and crown and the difference, if any, in position of the gingival line on the two sides. Measure the vertical distance from the most prominent point on the axial surface to the incisal edge or the tips of the cusps, and so on, making every measurement that can help in the formation of the drawing. In this way the outline of the section should first be traced inside the rectangle, then the dento-enamel junction, then the pulp chamber is shown, and finally the cementum. Before drawing the outline of the cementum, the section should be placed under the microscope, using the low power, and the cementum should be observed, studying it from the gingival line on one side of the section to the gingival line on the other.

It would be a waste of time to attempt to fill in the structure of the tissue of the entire outline, and only certain things are to be shown in these drawings. For that reason fill in three portions of enamel and dentin and three portions of cementum and dentin, using the low-power objective. Study first the bands of Retzius (page 68), and lightly indicate their direction. Study the enamel-rod direction, beginning at the gingival line at one side and following it around the crown to the other side. In a portion at the incisal edge, or on the occlusal surface, indicate the rod directions, and in the same way show them in a portion near the center of the axial surface on one side and near the gingival line. Follow the dentinal tubules which end next to the portions of enamel which have been filled in to the point where they open into the pulp chamber, and indicate their direction (page 139). In the same way fill in three portions of the cementum and the dentin under them—one in the gingival line, one near the middle of the root, and one in the region of the apex (Fig. 333).

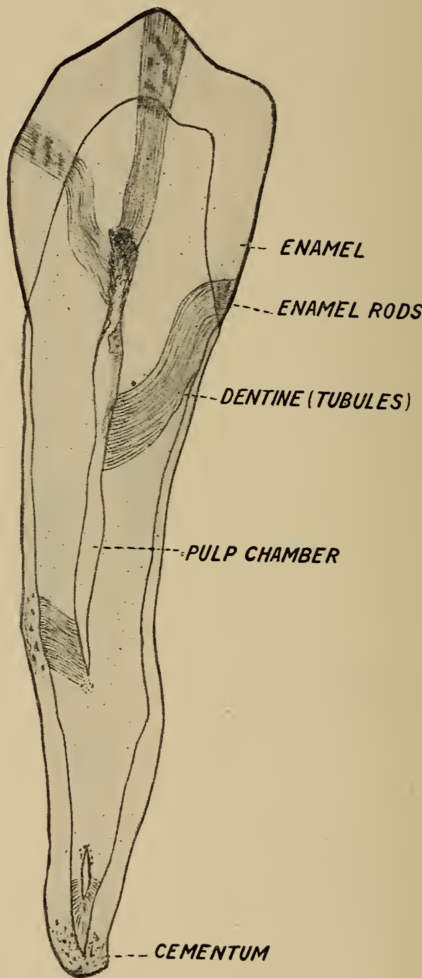


Fig. 333.—Outline drawing of longitudinal section, made as a study of the dental tissue. (Drawn by E. J. Schmidt.)

If any portion of the section has been lost in grinding, that portion should be indicated by dotted lines, and in the same way, if a portion of the crown has been lost by wear, the original form may be added in dotted lines.

Outline drawings should be made from each of the three classes of teeth—one from the incisor or cuspid, one from a bicuspid, and one from a molar, and a laboratory period should be devoted to each drawing.

PERIOD IV.

Isolated Enamel Rods.—Obtain from the desk a fragment of enamel which has been broken in the direction of the rods. Place a drop of distilled water or glycerin on the center of a clean slide. Moisten the broken surface with a drop of water and lightly scrape it with the blade of a broad, sharp, chisel, holding the edge parallel with the surface and the shaft at right angles to it. Dip the edge of the chisel in the drop of liquid on the slide, and the scrapings will be left. Cover with a cover-glass and study with the high power, using a small diaphragm. Fragments of enamel will be found made up of broken rods, some single and others in groups. Note the diameter of the rods and the appearance of the cross-markings, which will be seen if the light is properly adjusted. Draw as seen with the high power.

Repeat this operation, using enamel that has been immersed in 1 per cent. hydrochloric acid for a number of hours. Compare the appearance of the rods with those of the former specimen and make a drawing as seen with the high power.

Find an old tooth with a large carious cavity, remove the softened dentin without touching the enamel if possible. Lightly scrape the whitened inner surface of the enamel next to the cavity and mount the scrapings as before. Compare the appearance of these rods isolated by the action of caries with those of the previous specimen. Notice that the cross-markings are more distinct and the expansions and constrictions of the rods more prominent. Draw a few of the rods as seen with the high power, using the small diaphragm.

PERIOD V.

Minute Study of the Enamel and Dentin.—Select a field from one of the ground sections where the specimen is very thin, and, if possible, where the entire thickness of the enamel plate can be seen in one field with the $\frac{2}{3}$ objective. To select this field all of the enamel in the three sections should be carefully studied with the low power, and the one chosen in which the rods can be seen best and can be most easily drawn. Having selected the field, study the enamel with the high power, beginning at the dento-enamel junction. Note the form of the dento-enamel junction and the relation of the two tissues at this point. Note the diameter of the

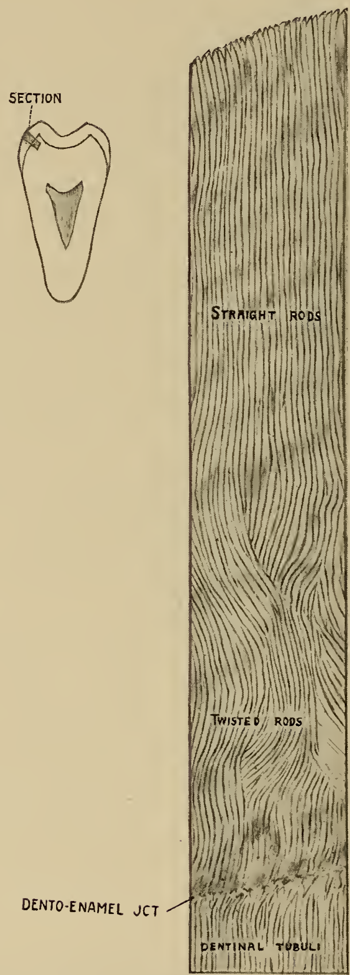


Fig. 334.—High-power drawing of the enamel. (Drawn by A. B. Hopper, 1902–03.)

enamel rods and estimate it, using a red blood corpuscle as a standard of measurement. Note the striation of the enamel (page 67). Using both the low and the high power, draw as accurately as possible the enamel from the surface to the dento-enamel junction, showing all the details of structure that can be made out.

The drawing should be made as long as the page will allow, and need not be more than an inch wide, and should include just enough of the dentin to show the dento-enamel junction and the character of the dentin at that point (Fig. 334). Notice the diameter of the dentinal tubules, comparing them with the red blood corpuscles and the enamel rods. Note the amount of matrix that separates the tubules. Observe the forking and the anastomosis of the tubules as they approach the enamel, and follow them as far as possible.

PERIOD VI.

Minute Study of the Cementum and Dentin.—With the low power study the cementum in the three specimens, looking for all the details of structure that can be made out (see page 154). In the gingival portions and often well toward the apex, especially if the tooth is from a young person, the cementum will be very thin and almost structureless in appearance. With the high power, fine lines parallel with the surface may be seen, which indicate the lamellæ. In the apical portion the cementum becomes much thicker, and it will be seen that each layer is thicker and consequently more easily seen. Little black spots looking like spiders will be found in larger or smaller numbers. These are the lacunæ with the canaliculi radiating from them. They were filled in life by cement corpuscles. Look for embedded fibers of the peridental membrane. In all of this work each field should be studied with both the low and the high power.

The inner layer of the cementum next to the dentin is clear and structureless, and the dentin adjoining it appears with the low power as a granular layer known as "the granular layer of Tomes." Studied with the high power, the appearance will be seen to be caused by irregular spaces in the dentin matrix communicating with the dentinal tubules and filled in life with protoplasm of the fibrils. Compare the dentin in the root with that in the crown (page 143).

After studying all the cementum in the three sections, select three fields, one from the gingival, one from the middle, and one from the apical portion of the root, and draw the tissues from the surface of the root to the pulp chamber. Show all the details of structure that can be made out with both low and high powers

(Fig. 335). With the high power search the cementum for the record of absorptions which have been refilled by cementum.

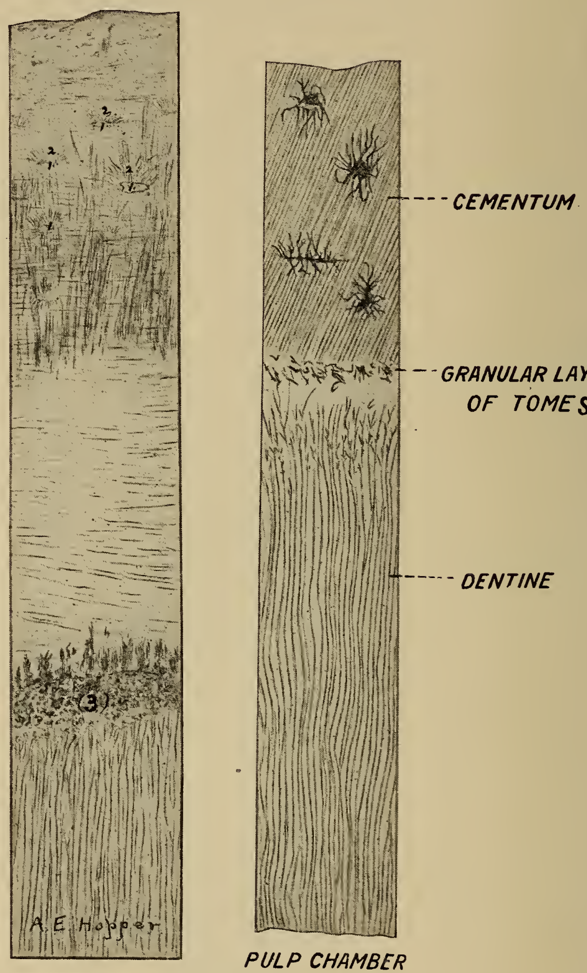


Fig. 335.—Cementum and dentin. (Drawn by H. J. Lund and A. E. Hopper.)

PERIOD VII.

Drawings of Typical Cavity Walls.—From the molar or bicuspid section select a field in the region of a groove or pit. Imagine a cavity to be prepared in this position. To help in this, an ink line may be made on the cover-glass by using a fine pen and India ink, or ordinary ink to which a little sugar has been added. Now, using both the high and the low power, study the direction of the enamel rods as they appear in the line of the cavity wall, and make a drawing showing the structural requirements for a good wall in this position. From any one of the three sections select a field in the gingival third of the labial or buccal surface and indicate the line of a cavity wall in the same way. Study with the low and the high powers the direction of the enamel rods as they appear in the line of the walls of the cavity, and make a drawing showing the structural requirements for good walls in these positions (page 107).

PERIOD VIII.

Outline Drawings from Transverse Sections of the Root.—The ground sections of the root have been prepared and should be brought to the laboratory in solution, ready for mounting. The three sections should be mounted together under one cover-glass, using balsam about the consistence of molasses. The sections may be studied at once, but after the day's work upon them they should have a spring clip adjusted to the cover-glass and be put away until the balsam is thoroughly hard, otherwise they may work out to the edge of the cover-glass. With the millimeter gauge measure the length and breadth of each section, multiply the measurements by twenty, and lay off a rectangle as in making the longitudinal drawings. Draw the outline of the section and the pulp chamber as accurately as possible before studying the section with the microscope. With the low power follow the dento-cemental junction around each section and draw it into the outline. Fill in half of each section, showing the direction of the dentinal tubules, the position and character of the granular layer of Tomes, the number and positions of the lacunæ, and the other structural characteristics of the cementum. In this study the record of the reduction of size of the pulp chamber which may be noted by changes in the direction and the character of the dentinal tubules (page 152). Label the section with the name of the root from which it was ground, your name, and the date.

PERIOD IX.

Study of Secondary Dentin and Cementum.—With the low power find a field where there is a distinct demarcation between dentin of earlier and later formation, and draw it accurately with the high power. Compare the size of the tubules, their number, their direction, and their diameter in the earlier with the later formed dentin. Is there any connection between the tubules of the two portions? Find a similar field from a longitudinal section and study in the same way, making an accurate drawing.

Search all of the ground sections with the low power until a field is found where the dentinal tubules are cut transversely. Adjust the high-power objective and study the field. Notice that by focussing up and down with the fine adjustment the tubules seem to move in a circle, showing the spiral course through the matrix. Using a red blood corpuscle as a standard, note the size of the tubules, their distribution in the matrix, and the amount of matrix separating them. Look for the appearance of Newman's sheath, which is that portion of the matrix forming the immediate wall of the tubule. Draw accurately one field as seen with the high power. Study the cementum from all the ground sections for an area showing absorption and rebuilding, and if found, draw one field with the high power. Draw five or six lacunæ with their canaliculi as seen with the high power, selecting as great a variety of forms as possible.

PERIOD X.

Ground Sections of Bone.—From a shaft of a femur or humerus saw a disk about one-quarter of an inch thick. In doing this notice the appearance of the marrow cavity especially as you look into it toward the articular ends. Saw the disk into sectors with an arc of about a quarter of an inch on the outer surface. From this piece saw two thin slices—one at right angles to the axis of the bone, the other parallel with it. These should be ground as directed in the introduction for the grinding of transverse sections of the root, and be brought to the laboratory ready to mount. They should be mounted in hard balsam as described in the mounting of longitudinal sections of the teeth. Label the slide with the name of the bone from which the section is taken and the direction in which it is cut. Study the transverse section with the low power, working out the arrangement of the lamellæ and the distribution of the subperiosteal and Haversian system bone (p. 213). Draw the tissue from the surface of the bone to the marrow cavity. This drawing should be not more than an inch wide and the full length of the page. With the high-power objective draw one or two Haversian systems.

Study the arrangement of the Haversian canals as seen in the longitudinal sections. With the high power draw at least three lacunæ, showing one cut lengthwise, one transversely, and one as seen from above.

PERIOD XI.

Decalcified Bone.—One of the bones from a small animal has been decalcified, embedded, sectioned, and stained with hematoxylin and eosin. Receive from the desk two sections, one of which is cut longitudinally, the other transversely. Mount in balsam in the usual way. Label the slide with the name of the animal, the bone from which it is cut, and the direction of the section. Study the transverse section with the low power, noting the bone corpuscles in the lacunæ, the tissue in the Haversian canals, and the marrow. With the high power draw one field showing two or three Haversian systems, one of which has been partially destroyed in the building of another. Draw with the high power one field from the marrow cavity. From the longitudinal section draw, with the high power, one field showing osteoblasts in a medullary space.

PERIOD XII.

Comparative Study of Subperiosteal Bone and Cementum.—For this day's work the previously mounted sections must be used, the longitudinal sections of the teeth, the transverse sections of the root, the ground and decalcified sections of bone. Study the cementum and the subperiosteal bone as shown in these sections and make one drawing of cementum and one drawing of subperiosteal bone to show the comparison in structure. Compare the regularity in form and arrangement of the lacunæ in the bone with the irregularity in form and position of the lacunæ in cementum. Note that in the bone the lacunæ lie between the layers; in the cementum they may be between the layers or entirely within a single layer. Compare the regularity in the arrangement and thickness of layers with the corresponding irregularity in cementum. Note the size, number and arrangement of the canaliculi radiating from the lacunæ in bone, and compare them with the canaliculi of the cementum.

PERIOD XIII.

Dental Pulp from the Unerupted Tooth of a Sheep.—An unerupted molar or premolar of a yearling lamb was removed from the lower jaw by splitting the bone. The pulp was pulled out of the partially-formed dentin embedded in paraffin, sectioned, stained with hematoxylin and eosin. Bring to the desk a clean slide with a drop of balsam upon the center of it and receive a section. Label the slide: "Pulp from unerupted tooth of sheep, stained with hematoxylin and eosin." Study first with the low power. Upon the circumference of the section the layer of odontoblasts may or may not be shown, depending upon whether in the removal of the pulp the fibrils have pulled away from the dentin, or the odontoblasts have been pulled off from the surface of the pulp. They are usually present, at least in spots. Note the number and arrangement of the bloodvessels and the distribution of the connective-tissue cells. With the low power draw a portion from the surface to the center, showing the layer of odontoblasts, if present. With the high power draw one field showing a bloodvessel and the connective-tissue cells, taking particular pains to represent their forms correctly. If there are any odontoblasts present draw one field showing them and the layer of Weil (see page 167).

PERIOD XIV.

Dental Pulp, Normal Human.—A number of human teeth were cracked immediately after extraction and the pulps removed from the pulp chambers. They were embedded in one block of paraffin, sectioned, stained with hematoxylin and eosin, and are ready to be given out. Bring to the desk a clean slide with a drop of balsam on the center and receive a section. Label the slide: "Transverse section of pulp from human teeth." There will be several sections in this specimen, each from a separate pulp. With the low power follow the circumference of each section, looking for places where odontoblasts are present. Find the best field in the specimen and draw the layer of odontoblasts as seen with the high power. Notice the fibrils which have been pulled out of the dentinal tubules projecting from the ends of the odontoblasts. If the section is parallel with the long axis of the cells, they will appear as tall columnar cells with a nucleus in the deeper end. If it is oblique to their axis the layer may appear as two or three layers of oval cells. Just beyond the odontoblasts the layer of Weil will be seen, usually appearing as a clearer layer containing few cells and about half as wide as the odontoblasts. Beyond this the connective-tissue cells are thickly placed for a short distance, and still deeper they are more widely scattered and about evenly distributed in the rest of the pulp.

With the high power draw one field to show the form of the connective-tissue cells of the pulp. With the low power study the distribution of the bloodvessels in all of the sections. Select the best section and draw the entire section to show the size, number, and arrangement of the large bloodvessels. With the high power draw a single field to show accurately the structure of a bloodvessel wall.

PERIOD XV.

Dental Pulp, Pathologic Human.—By the coöperation of the man in charge of the extracting room, or an extracting specialist, teeth with living but inflamed or hyperemic pulps were dropped as soon as extracted into a fixing fluid. The teeth were afterward cracked and the pulps removed, embedded, and sectioned as before. Bring to the desk a clean slide with a drop of balsam on its center and receive a section. Label the slide: "Pathologic pulp from human tooth stained with hematoxylin and eosin." Follow the same routine in studying these specimens as in the case of the normal pulp. It is impossible to tell just what conditions will be present. Compare the size and number of the bloodvessels with those in the normal tissue, and the character and distribution of the cellular elements. Look for nodules of calcoglobuli, especially in the inflammatory specimens, and make a diagnosis of the condition, as shown in the specimen. See the chapter on the Structural Changes in the Pulp and Pathological Conditions for further assistance on the work in this material.

PERIOD XVI.

Endochondral Bone Formation.—A forming bone from a human fetus has been embedded, sectioned, and stained with hematoxylin and eosin. Receive a section from the desk and mount as usual. Study the specimen with the low power, identifying first the general arrangement of the tissues, following from the unchanged cartilage to the development of bone. Notice the subperiosteal layers on the surface. Make a sketch of a sufficient part of the section to show the changes from the typical hyaline cartilage to the young bone. With the high power draw one field from a primary marrow cavity, showing osteoblasts laying down lamellæ on one of the spicules, and one field showing osteoclasts.

PERIOD XVII.

Bone Growth.—A piece of a long bone from a very young animal has been embedded and sectioned transversely to the shaft. Sections have been stained in hematoxylin and eosin, to be mounted as usual. Label the slide: "Growing bone cut transversely, stained with hematoxylin and eosin." Study first with the low power. On the surface of the section will be seen the periosteum, in which the fibrous and osteogenetic layers can be easily recognized. Bone formation is actively going on, laying down lamellæ under the periosteum which are being transformed into Haversian system bone. With the low power draw a portion of the section from the periosteum to the center of the bone. With the high power draw a field showing the osteoblasts of the periosteum, a field showing the absorption of subperiosteal bone to form a medullary space, and a field showing osteoblasts in a medullary space.

PERIOD XVIII.

Periosteum from Attached Portion.—From a young kitten a portion of a bone in a region to which muscles are attached to the periosteum was carefully dissected out, removing the attached muscle, and the tissue embedded in celloidin, the sections cut parallel to the axis of the bone and perpendicular to its surface. They have been stained in hematoxylin and eosin, and are ready to be given out. Receive a section and mount as usual. Label: "Periosteum from attached portion, stained in hematoxylin and eosin." Study the specimen first with the low power. The outer fibrous layer of the periosteum will be seen with the muscle fibers attached to it and the osteogenetic layer with the greater number of cells taking the stain more deeply. Draw with the low power, showing the tissues from the surface of the periosteum well into the substance of the bone. With the high power study the attachment of the muscle fibers to the outer layer of the periosteum, the character and arrangement of the fibers of the outer layer, the interlacing of the fibers of the outer and inner layer, the cells, and especially the osteoblasts of the inner layer and the penetrating fibers that are built into the bone. Draw the thickness of the periosteum as seen with the high power, showing the details of structure as accurately as possible.

PERIOD XIX.

Gingivus and Gum Tissue.—The gingivus and gum tissue covering the alveolar process down to the point of reflection on to the cheek was dissected away from the teeth and jaw of a sheep. The tissue was embedded in paraffin and sectioned parallel with the long axis of the tooth. The sections have been stained with hematoxylin and Van Gieson, and are ready to mount. Bring to the desk a clean slide with a drop of balsam on the center and receive a specimen. Label the section: "Gingivus from a sheep, stained with hematoxylin and Van Gieson." By this staining the cellular elements will have a brownish color, the nuclei dark, the protoplasm lighter, the white fibers should be bright red, and the elastic fibers yellowish. It is a specially good stain for connective tissue. Study with the low power. The epithelium will be stained a brownish yellow or purple. It is a stratified squamous epithelium made up of many layers of cells and with a distinct horny or corneous layer on the surface from the crest of the gingivus to the point where the mucous membrane is reflected on to the cheek, or where it ceases to be attached to the gum. This layer is yellowish in color, and is made up of closely packed scales having no nuclei. They are the remains of epithelial cells from which the protoplasm is gone, leaving only the horny material which it had produced. The portion of the epithelial lining the gingival space has no corneous layer, nuclei being seen in the cells at the surface. The cells are larger and more loosely placed. The connective-tissue papillæ and the projections of epithelium which are between them are extremely long. In the epithelium covering the alveolar process the connective-tissue papillæ are broader and not so deep, and the cells are much more compactly arranged. At the point of reflection on the cheek the epithelium changes its character abruptly, the corneous layer disappears, the surface cells showing nuclei, the epithelial layer is thicker and made up of larger and more loosely placed cells. This change in the structure explains why the epithelium is easily broken where a movable portion of the membrane passes over the edge of an artificial denture. When an infection reaches the connective tissue a sore is produced that requires some time to heal.

Study the connective tissue, which is made up of coarse, wavy bundles of white fibers taking the red stain. In the gum tissue, that is, the portion of the section covering the alveolar process, the bundles are very large and form a very coarse network. Beyond the point of reflection the bundles are finer and more delicate in their arrangement. Elastic fibers take the yellowish stain. Notice the bloodvessels in the connective tissue and the capillaries in the papillæ. With the low power draw the entire section so as to show the character of the epithelium and the fibrous tissue in the three parts.

With the high power draw the thickness of the epithelium lining the gingival space and at the point where the membrane is reflected to the cheek.

PERIOD XX.

Peridental Membrane, Transverse Gingival.—The lower jaw of a young sheep was sawed through between the teeth, cutting the jaw into blocks each containing two teeth. The crowns were broken off or opened so as to admit the fluids to the pulp tissue. The tissues were decalcified, embedded, and sectioned at right angles to the axis of the tooth. They are cut from the gingival portion, and have been stained with hematoxylin and eosin. Receive a section and mount as usual. Label the slide: "Peridental membrane, transverse gingival, stained with hematoxylin and eosin." A similar block of tissue preserved in alcohol will be found at the desk. This should be observed so as to study out the relation of the section to the gross appearance of the tissue.

Holding the section to the light, observe the distribution of the tissue. Two roots will be seen cut across. Observe the epithelium on the labial and the lingual, and possibly also that lining the gingival space lying next to the root of one of the teeth. By the aid of the low power sketch the outline of the entire section to show the distribution of the tissues. Note the demarcation where the finer fibers of the peridental membrane unite with the coarser mat of gum tissue. Beginning at the center of the labial surface, follow the fibers springing from the cementum to where they are lost in the gum tissue or attached to the approximating tooth. Draw the portion of the membrane between the two roots, accurately representing the arrangement of the fibers. The epithelial structures will be seen lying between the fibers close to the cementum, and should be shown in the drawing (p. 248).

With the high power study the cementoblasts and the epithelial structures. Make a drawing of one field, showing all the details of structure as accurately as possible.

With the high power draw one field showing the fibrous tissue between the roots and the relation of the fibroblasts to them. This field should include a bloodvessel.

PERIOD XXI.

Peridental Membrane, Alveolar Portion, Transverse.—The sections for this work have been cut from the same block as the preceding, but are in the occlusal third of the alveolar portion and as close to the border of the alveolar process as possible. Receive a section. Mount as usual and label the slide: "Peridental membrane, alveolar portion, transverse, stained with hematoxylin and eosin."

Study the general arrangement of the tissues and make a sketch as in the case of the previous specimen. Note the muscle fibers from the muscles of the lip attached to the periosteum on the labial surface of the process, the bone of the labial plate, the septum separating the alveoli, the peridental membrane filling the space between the bone and the surface of the root, the layers of the cementum, the dentin and the pulp.

After studying the specimen with the low power as carefully as possible, draw the peridental membrane surrounding one root, including the thickness of the labial plate of bone with its periosteum and a part of the lingual plate. In this drawing represent accurately the fibers of the peridental membrane, their arrangement in the bundles, and the relation of the bundles to each other and the bloodvessels. To do this the fine adjustment must be used to obtain ideas of the third dimension of space. With the high power draw one field from the wall of the alveolus, showing the attachment of the fibers to the bone, the osteoblasts on the surface of the bone, and the other cellular elements. This field should include a bloodvessel. With the high power draw the thickness of the cementum at some point where a specially strong bundle of fibers is attached. This should show the fibers embedded in the cementum, cementoblasts on the surface, and the branching and interlacing of the bundles.

PERIOD XXII.

Longitudinal Section of the Peridental Membrane.—The lower incisor of a young sheep was removed from the jaw by sawing through between the teeth, leaving two teeth in each block. The crowns of the teeth were broken off near the level of the gum so as to admit the reagents to the pulp chamber. The tissues decalcified, embedded in celloidin, and sectioned. They were cut through from labial to lingual, and only the ones from the central portion used. They have been stained in hematoxylin and eosin and are ready to mount. Mount the section as usual and label the slide: "Longitudinal section through the peridental membrane of a sheep, labiolingual, stained in hematoxylin and eosin." First hold the section up to the light and note the relation of the tooth to the bone and the soft tissues. Study the section with the low power and make a sketch showing the general distribution of the tissues. Show the pulp chamber, dentin and cementum, bone, periosteum, gum tissue, and epithelium. Do not attempt to fill in the drawing more than diagrammatically, for it would require too much time. The object of the drawing is to get the general relation of the tissue before studying parts of it in detail. Compare the form of the labial and the lingual gingivus and make a drawing of the lingual, showing the details of structure as far as the border of the process and as accurately as possible. With the high power draw the thickness of the epithelium lining the gingival space. Study the fibers in the occlusal third of the alveolar process and make a drawing to represent them accurately, showing the cementum at one side and the bone at the other. The entire length of the root can seldom be got in one section on account of the curve of the tooth, so that the fibers can probably be studied to advantage in the occlusal third of the alveolar process only. Draw one field with the high power showing the bloodvessels.

PERIOD XXIII.

Tooth Germ.—The head of an embryo pig was embedded in paraffin and sectioned at right angles to the snout. The sections begin in the region of the incisors and far enough back to cut through the nose cavity. They have been stained in hematoxylin and eosin. Bring to the desk a clean slide and receive a section. Label the slide: "Tooth germ, stained with hematoxylin and eosin."

The general form of the section will depend on the position of the section through the head. At the desk is the head of a similar embryo preserved in alcohol. This should be observed so as to determine from the section its relation to the head. By holding the section to the light and the use of the low power, make a sketch of the entire section. Note the epiblast covering the outer surface and lining the nose and mouth cavity. The mass which is to form the tongue lying between the roof of the mouth and the mandibular arch. If the section is in front of the angle of the mouth there will be no connection between the upper and lower parts of the section. Notice the separation of the nose cavity into right and left by a septum containing cartilage, and the projections of cartilage from the side walls which will form the turbinate bones. On either side of the septum where it joins the palate will be seen little structures known as Jacobson's organ, which later disappear. Notice Meckel's cartilage in the mesodermic mass of the mandible. In the epiderm of the outer surface the beginning of the formation of hairs are to be seen.

With the low power follow the epiderm lining the mouth cavity and look for the tooth germ. In each section there are four chances for tooth germs, one on either side in the upper and lower arches. Select the best one and draw it as seen with the low power. The appearance will depend entirely upon the stage of development.

With the high power draw enough of the enamel organ to show the arrangement of the cells in the outer and inner tunics and the stellate reticulum.

PERIOD XXIV.

Tooth Germ.—Sections have been prepared in the same way as in the preceding, but from the head of an older embryo, in which the tooth germs are completely formed and calcification is ready to begin.

Receive a section, mount, and label as before, and draw the outline of the entire section. Note the changes in form and in the tissue elements from the previous section. Bone formation has begun both in the mandible and the maxilla. The amount and distribution of this should be carefully studied.

With the low power draw the entire tooth germ, selecting the most typical one in the section. With the high power draw one field showing ameloblasts, odontoblasts, and a portion of the papillæ. Find a field in which bone formation is going on and draw it accurately with the high power.

APPENDIX CHAPTER I.

THE GRINDING OF MICROSCOPIC SPECIMENS, USING THE GRINDING MACHINE.

By G. V. BLACK, M.D., D.D.S., Sc.D., LL.D.

The Machine.—The basis of this machine is the larger watchmaker's lathe known as No. 2. It must swing 4 inches, the length of the bed must be 12 inches, and be good and solid. A test should be made of the alignment of the lathe head to see that this is exact. If there is any inaccuracy, another lathe should be selected. The power should consist of one of the largest and strongest electric lathes, or motors, made for the use of dentists. This power should be transmitted to the lathe through an overhead shaft of a length that will give good room to operate the lathe without the motor being in the way. A pulley may be placed on the left end of the shaft of the motor on one of the brass carriers for grinding wheels. This pulley should carry a good quarter-inch round leather belt. Its diameter should be $2\frac{1}{2}$ inches. The pulley on the right hand end of the shaft above should be 5 inches. This will reduce the speed one-half and double the power. On the left end of the shaft should be placed a copy—reversed—of the pulley on the lathe-head, which has 4 grooves. This gives good varieties of speed with each speed of the motor. Another small pulley will be placed near the center of the length of the overhead shaft, the purpose of which will be explained later (Figs. 336 and 337).

The grinding apparatus is built upon a base fitted to the lathe bed in the same way as the lathe head, or tail-piece. It has one main shaft parallel with the lathe bed, in good and sufficient bearings to maintain accuracy of alignment and perfect steadiness for long-continued usage (see Figs. 336 and 337). This shaft moves freely lengthwise, or back and forward, while turning slowly in its bearings. On the end of this shaft next to the lathe head—the forward end—there is a larger portion, or ring, and this end terminates in a threaded nipple, upon which the removable grinding disks are screwed firmly against the face of this larger ring, to

Fig. 336

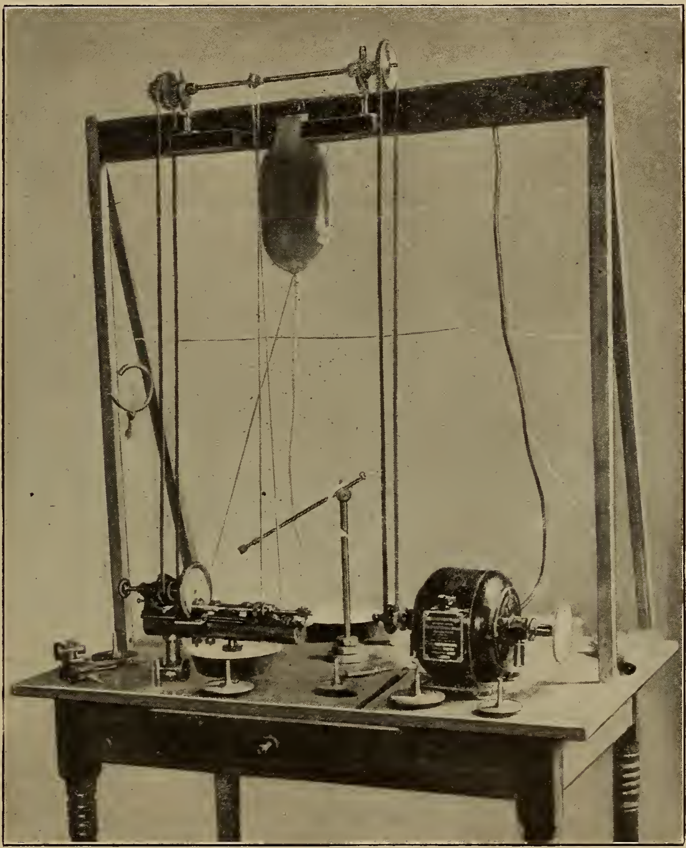
Figs. 336 and 337.—A general view of the grinding machine, showing particularly the arrangement for transmitting the power from the electric motor to the machine that does the work. All of this may be made out by reference to the picture while following the text. The bed of the little lathe on the left hand is $12\frac{1}{4}$ inches long, which gives a good idea of the general dimensions.

The water is delivered to the grinding stone from a rubber bag or bucket hung on the frame above through a rubber tube to the metal tube on a movable stand, which may be so placed as to bring the brush at its end against the stone. This stand and brush are better seen in Fig. 337.

secure accuracy of adjustment. The use of these disks will be more fully explained later.

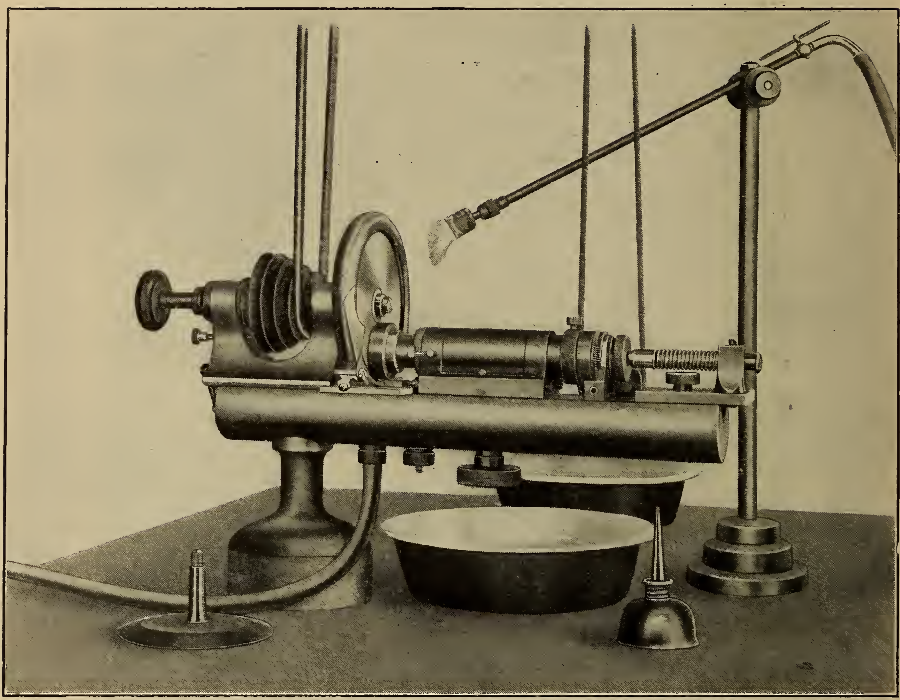
On the rear end of this shaft, just back of its rear bearing and abutting against it, a large movable nut is placed. This is provided with a thumb screw by which it is made fast at any point desired. Turning this forward pulls the shaft back from the grinding stone. Turning it backward allows the shaft to move forward

Fig. 337



against the stone. It has also a finger reaching back over a graduated disk just to its rear. This disk is made fast on the shaft, and the two together constitute the micrometer, by which the thickness to which specimens are ground is measured. The movable nut has 40 threads to the inch. The graduation of the disk is on the same principle as that on the screw calipers used by machinists for fine measurements—one-thousandth of an inch—but as this disk is $1\frac{1}{8}$ inches in diameter, the graduations of thousandths are so

Fig. 338



Figs. 338 and 339.—*The lathe with the grinding machine* mounted upon it in position for work. On the left next to the lathe head is the grinding stone surrounded by the spatter guard, which gathers all of the water from the wheel and delivers it through its hollow post into a rubber tube below the lathe bed, which conveys it to a conveniently placed receptacle. The watei comes from a ıubber bag or bucket hung on the overhead frame (see Fig. 336) through a rubber tube to the metal tube mounted on a movable stand so that the brush through which it passes may be placed against the stone. The grinding machine proper is secured to the lathe bed by the larger thumb-screw seen below. The point-finder is seen at the foot of the spatter guard, and is secured by the middle thumb-screw seen below the lathe bed.

The shaft of the grinding machine (6 inches long) ıuns through its whole length, but is completely covered in by its housings to protect its bearings from grit, except at its forward end (next to the grinding stone). This part is protected by a swaddle held by a ring, which keeps the working bearing clean. On this end the grinding disk is seen almost touching the stone. The micrometer is on the other end of the shaft next back of the frame of the grinding machine. Next back of this is a toothed wheel made fast to the shaft. This is actuated by the middle one of the belts descending from overhead (Fig. 336, the left hand belt in Fig. 337). This belt passes over a wheel hidden from view and through a small worm shaft turns the main shaft. Pressure for the grinding is supplied by a plunger actuated by a spiral spring seen at the extreme right-hand end.

wide that one-quarter of one-thousandth may readily be used. It differs in plan, in that both the graduation and the parallel lines

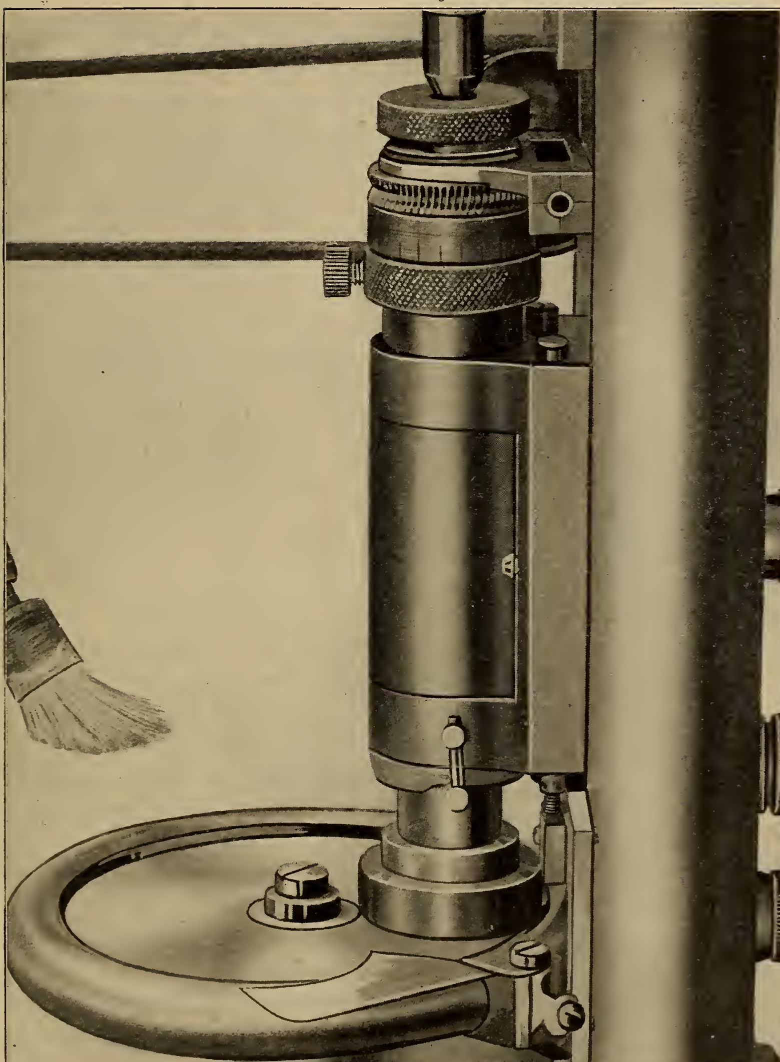


Fig. 339

are placed upon this disk. On the machinist's micrometer the lines are placed on the shaft and the graduations on the nut. The graduation is read from the side of the finger on the movable nut, and the lines are read from its end. It is a very perfect micrometer (Figs. 338 and 339).

The forward movement of the shaft when grinding, and also the pressure exerted upon the stone, are furnished by a tail-piece placed behind it and attached to the lathe bed. This has a plunger actuated by a spiral spring, which pushes the shaft forward against the stone. The amount of pressure exerted in the grinding is controlled by the amount of compression of this spring in fixing the piece to the lathe bed. It may be much or little, as desired. Usually very little pressure is used. When the movable nut has come against the frame in which this shaft turns, the machine may continue to run, but the forward movement of the shaft stops and the grinding ceases in consequence. Therefore there is no danger of grinding a specimen thinner than the measurement fixed upon. The further arrangement for finding this measurement will be described later.

On the rear portion of the graduated disk, or wheel, a portion or space is toothed, and connected with a worm pinion or threaded shaft by which the main shaft is turned in its bearings. A belt is attached over a wheel on the end of this worm shaft, and extends to the third wheel, previously mentioned, on the overhead shaft. When this belt is adjusted and the motor started, it causes the main shaft in the grinding machine proper to turn slowly on its axis, while being pressed against the stone by the tail-piece. By this arrangement every part of the specimen fixed on the grinding disk is brought successively against every part of the rapidly revolving stone, and is cut perfectly level in all of its parts.

The Grinding Disks.—The grinding disks are of brass, accurately turned $\frac{3}{8}$ inch thick, and $1\frac{3}{8}$ inches in diameter. They have a threaded hole $\frac{1}{4}$ inch deep in the back to fix them to the nipple on the forward end of the shaft of the grinding machine. A machine should have a half-dozen or more of these, lettered or numbered on the edge, so that records of each may be made when measuring preparatory to mounting specimens for grinding. As the mounting of specimens on others of these may proceed while the grinding on one is going on (for the machine, being automatic, needs little attention), this number at the least is necessary for rapid work.

The machine may be stopped and the disk removed from the shaft by a few backward turns, the progress of the grinding examined, the disk returned for further grinding, etc., at any time during the progress of the work. The face of the disk, which should be perfectly flat and parallel with the face of the stone, should always be perfectly bright, so as to reflect light through the specimen when it becomes thin. This enables one to judge very closely of the thickness by the eye (after sufficient practice), that sometimes proves a valuable check on the setting of the measurement in the beginning.

The Point-finder.—This is a piece of steel one-eighth of an inch thick, fitted to the lathe bed and set against the face of the lathe head, and made fast by a thumb-screw passing through the lathe bed from below. It has a strong arm which passes around other fixtures between the lathe head and the forward end of the base of the grinding machine. It is provided with a set-screw, by which a range of variation can be made in the distance of the forward end of the frame of the grinding machine from the lathe head. When this is in place and the measurement of a disk has been made and recorded for the grinding of a specimen to a specified thickness, the machine may be taken to pieces and set up again and the grinding proceed without fear of disturbing the measurement, so long as the set-screw in the point-finder is not moved. It is often necessary during grinding to loosen the grinding machine from the lathe bed, slide it back to adjust something, to remove disks for examination of the progress of the work, etc. This point-finder, by preserving the distance between the lathe head and the grinding machine, enables one to do this at will, and again find his exact point of measurement simply by sliding the frame of the grinding machine forward against the set-screw of the point-finder. This little device seems absolutely necessary to the highest usefulness of the machine.

Lap Wheels and Grinding Stones.—I began my work of grinding specimens by the use of lap wheels, but soon discarded them because they were dirty. They cut much quicker than stones, however, and may be used for the bulk of the work when much grinding of very hard material is to be done. They are not necessary in grinding teeth, bone, etc., but in grinding the harder fossils, especially those impregnated with the silica, and in some geological work they become necessary.

The best lap wheel I have used is an aluminum wheel. Brass or iron will do the work, but aluminum holds the grit better, cuts with lighter pressure, and does the work quicker. In using these I have fed them continuously by hand with carborundum powder in soapy water, using a brush.

The Stones.—Anyone who is doing much grinding should have a good supply of stones. I have a pair of carborundum wheels, a pair of emery wheels, a pair of India oil stones, and a pair of Arkansas stones. In each of these pairs one is fine and the other coarser grit. Every stone is dressed to a perfect face on the lathe head where it is to do its work, with a black diamond held in the slide rest.

These stones, when put in good shape, seem capable of doing an unlimited amount of work. The conditions of the grinding prevents them from getting out of true. All that seems necessary is to roughen them a bit with a picking wheel when they become too smooth to cut well. For this purpose a much smaller picking tool than the smallest sold for the general mechanical uses seems desirable. This picking wheel has sharp teeth of the hardest steel possible on its periphery. It is held in a handle in such form that the wheel is free to turn. In use it is held against the rapidly rotating stone and slowly passed over its entire surface. It may be held in the hand aided by a tool rest, or may be arranged for use in the slide rest, which is the better form for this work.

Watering the Stones.—In grinding, the stones are kept wet in *running ice water*. A balsam that is too soft to hold a specimen for grinding in water at room temperature will hold it perfectly in ice water, because it is much harder when cold. For this purpose, a receptacle for ice is hung on the frame that holds the overhead shaft, and filled with bits of ice and then filled with water. Both the ice and the water must be clean, for the opening in the tube where it passes the valve which regulates the flow is very small, and a little bit of dirt or trash might stop the flow. In this case the specimen being ground would be burned instantly. A bucket, or a large rubber bag, will answer for this purpose. Then an ordinary rubber tube answers to conduct the water. It is best to have this rubber tube to connect with a metal tube mounted on a stand that may be placed in any position wanted to deliver the water to the stone. This metallic tube is provided with a valve for the regulation of the flow. In its final end it should be provided with a brush of rather long bristles, into which the water is delivered and spread upon the stone. This brush is made upon a short tube fitted into the end of the metal tube. To make this brush, first cover the plain part of the small brass tube with thick shellac dissolved in absolute alcohol. Place a layer of the bristles around it and wrap them tightly with a fine, strong thread. Then place more shellac over this and another layer of bristles. Continue this until the brush is large enough. Then wrap thoroughly with a cord in shellac, let it dry, and then trim it up. Two of these have served for four years of fairly hard usage.

Waste Water.—*A spatter guard* is made by bending a $\frac{5}{8}$-inch round brass tube into a circle, the inner diameter of which is the size of the stones used, and brazing the ends together solidly. Then this is fixed in the lathe and one-fourth of its inner circular diameter is turned away. The grinding stones will then go inside this. Then this piece is provided with a foot and hollow post and fitted to the lathe bed with a washer and nut, the same as other pieces are attached. This catches all waste water and through a rubber tube attached to the end of its hollow post under the lathe bed delivers it into a receptacle so placed by the table as to receive it. This prevents all of the spattering of water which would be thrown from a rapidly revolving wheel without it. If it should be inclined to run over when a very full stream is wanted, a piece of rubber dam may be stretched over the foot and pulled to its upper end. This may be caught under the guard in fastening it to the lathe bed, and will deliver any overflow into a receptacle placed to receive it. In this way nothing is wet or spattered with water.

Preparation of Material.—In the preparation of material, such as teeth, bone, etc., in histological work of ordinary delicacy, the specimen is first ground flat on one side by hand on a rough stone 4 inches in diameter, on the motor, and finished perfectly flat on one of the finer stones on the lathe head. The piece is then washed clean and placed in absolute alcohol for a sufficient time to remove all traces of water, or, when cracking or injury from shrinkage is not feared, it may be dried in the warming box. Then when dried and warmed to about 120° F., it is ready to mount with balsam on the grinding disk for grinding.

Management of Balsam.—I suppose the management of balsam will always be a difficult problem with many persons. Many, however, learn it quickly. One may take the dry balsam and dissolve it in xylol, and filter it at a high temperature, say 110° or 120° F. Or one may use the prepared balsam for microscopic mountings. In either case it must be evaporated until stiff enough so that it will move rather sluggishly at 110° F., but will be fluid at 120° or 130° F.

Spiders and Dogs.—For using this another bit of apparatus is necessary. A circular piece of steel made flat on the upper surface is mounted on three legs $1\frac{1}{2}$ to 2 inches high. The steel disk should have two rows of holes around its periphery, the one row $\frac{3}{8}$ inch inside the other. A hard-rolled tool-steel wire, or rod $\frac{3}{32}$ inch in

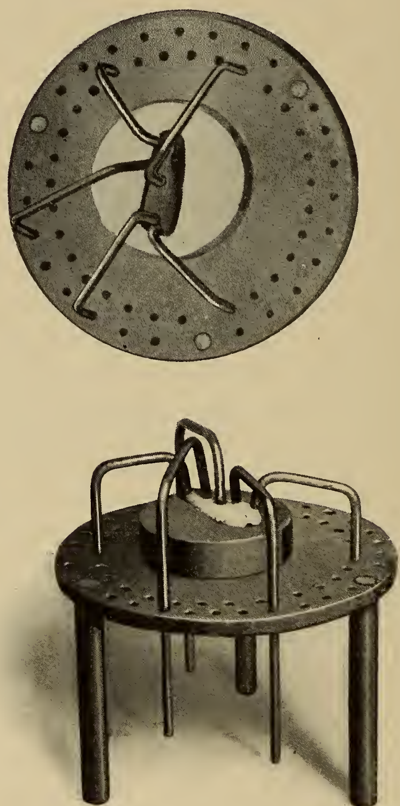


FIG. 340.—The spider with a grinding disk upon it and a specimen laid on and secured by bent rods called dogs. When these dogs are placed and pressed down through the holes in the disk of the spider, they hold fast. With a little pressure of the finger outward on the end of the rod below the disk of the spider, the dog slips up and is loose. The disk of the spider is three inches in diameter.

diameter, should exactly fit these holes. These rods should now be bent at right angles with a short nib on the end, bent again at right angles, so that it will point downward when the free end of the rod is set into one of the holes. The length between these two angles should vary from $\frac{3}{4}$ to $1\frac{1}{2}$ inches in three dozen or more pieces which should be prepared. The end which goes in the holes should be cut so that it will not quite reach the surface of the table when dropped into the holes with the end of the nib on the surface of the circular plate. These rods are called "dogs" (Fig. 340).

With this arrangement a warming box arranged with a thermostat to maintain an even temperature, sufficiently high to soften the stiff balsam, is used. The specimen, the balsam, the grinding disk, and the "spider" are placed inside, and allowed to rest until they have reached the temperature desired. Then working quickly, a sufficient amount of balsam is placed on the grinding disk, and the specimen laid on it. This should be pressed down until it is seen that all space under it is filled with balsam, but no considerable excess should be used. It is well if this rest so in the warming box for fifteen minutes for the balsam to soak well into the specimen. Then the grinding disk, with the specimens, should be laid on the spider and one of the dogs dropped into one of the holes in the steel plate, that will bring its nib on to a part of the specimen chosen. Then another, and still another, should be placed, each with its nib on a different part of the specimen, so that every part of it may be pressed flat on the disk. More dogs should be added if necessary. Now each in turn is pressed down a little, one after another, until all are exerting about all the force the spring of the rods will exert without permanently bending them. In this condition the whole thing is again enclosed in the warming box.

At this time any number of specimens of teeth or bits of teeth, bone, etc., that the face of the disk will hold may be placed on the disk, and all may be ground together. Four to six lengthwise sections of incisor or cuspid teeth may be placed at once, or eight to twelve cross-sections. It seems to be best practice, however, not to load the disk too heavily. Four lengthwise sections will grind better than six, as a rule.

Now, after the loaded disk had remained in the warming box until all balsam that will come has been squeezed out from under the specimens, all excess of balsam should be very carefully removed, or wiped away, close up against the specimens. Nothing clogs a stone and stops its cutting more effectually than balsam smeared over it, and every excess that may come against the stone should be got out of the way.

When this is done the whole thing should be returned to the warming box for from one to four hours, so that it may dry some about the margins at least. Then it may be removed from the warming box and allowed to cool, and await convenience in grinding. It should, however, remain secured on the spider by the dogs if it is to wait more than a few hours, for the disposition of dentin to warp in drying may pull some part of the specimen from the disk. Under these conditions, two or three days, or a week, will do no harm.

When the grinding is completed, the disk is removed from the machine and the specimens flushed with clean water, and dried by the pressure of a soft napkin folded to several thicknesses, or clean pieces of waste cotton fabric may be used. Then the disk with its specimens should be laid in a dish and sufficient xylol added to cover it, and allowed to rest until the balsam has been dissolved and the specimens released. This will usually require from twenty to thirty minutes, or sometimes as much as an hour. When the specimens are very thin they loosen much quicker than when thick. Any material not penetrated by xylol, as silicified petrifactions and stones, require much more time.

When the specimens have loosened, they are ready for permanent mounting for microscopic study.

Rapidity of Grinding.—In order to make rapid progress in grinding specimens, one should have six to ten grinding disks, nearly as many spiders, and a large supply of dogs. The machine is so nearly automatic in its action that it needs but little watching, so that the preparation may be going on while the grinding is in progress. One of the principal points that needs attention is the flow of water. But if the water and ice placed in the receptacle are clean and free from dirt or trash that may stop the flow of water, the only care is that the quantity of water is kept up. The vessel should be large enough to hold a supply for several hours. If the stone should run dry, the specimen would be destroyed in a few seconds.

Setting the Measurement of Grinding Disks.—When beginning any considerable series of grindings, the first thing of importance is to try out and obtain a record of the measurements of each grinding disk for the particular stone that may be selected for finishing. I find that most persons, after some practice, prefer to use a fine stone for the entire grind. In grinding teeth, after roughing down the surface that is to form the specimen, the back is also ground away to a flat surface that will better accommodate the placing of dogs in mounting on the grinding disks. These may be made quite thin and reduce the grinding with the fine stone. Then the stone selected is placed in the lathe head, seeing to it carefully that the face of the stone is clean. Then the grinding machine is brought up in contact with the set-screw of the point-finder. The tail-piece is placed in position and pushed up so as to make some pressure on the shaft. Then, with the large nut the shaft is so adjusted that the grinding disk being tried comes close to the stone but does not touch it. Now start the machine and note the running carefully, and while doing so catch the adjusting nut of the micrometer and move it one-thousandth at a time, and listen for the first touch of the disk to the stone. The moment this is heard, quickly reverse the movement of the adjusting nut and separate the disk from the stone. Try this again and again, until you feel very certain of having detected the first touch of the stone on the disk by moving the adjusting nut half or a quarter of $\frac{1}{1000}$ inch. At last, while it is touching, stop the machine in a position to see the finger on the adjusting nut, and read the measurement and enter it on your record for that disk. In setting for a grind with this disk, turn the adjusting nut so as to draw the grinding disk back from the stone $\frac{3}{1000}$ inch. When the specimens to be ground are mounted on this disk, place it back on the machine, start it, seeing that the iced water is running first, and let it run until it ceases to cut, which it will do when the forward movement of the shaft is stopped by the contact of the adjusting nut of the micrometer with the rear bearing of the shaft.

Then remove the disk and examine the specimens carefully. If the placement has been accurate, the specimens will be too thick. Replace the disk carefully and turn the nut forward so as to grind one-thousandth of an inch thinner, or one may do only a half of one-thousandth at a time. Repeat this until the section seems to be thin enough. Then remove and mount the sections and judge them with the microscope. By this time one will have arrived at an accurate measurement of this disk, and the record will be trustworthy for other grinds, and will not have to be repeated until the wearing of the stone begins to leave the specimens a bit thick. Then a half-thousandth of an inch will bring it right. And so on, and on. Each disk will be treated in the same way for each stone used, and if one is doing much grinding all will be running on their records, and all go smoothly. Recently a man who was grinding sections of teeth for me made all of the preparations, preparatory grindings, and disk mounts, ground and removed from the disks ready for mounting forty full-length sections of central incisors in six hours, and had his lunch during the time. Every section was complete, was even in thickness in every part, and all practically the same thickness—a thickness chosen for the special studies in hand.

Grinding Frail Material.—While the machine facilitates the production of the more ordinary sections to such a degree as to be indispensable to one having many grindings to do, it is in the production of sections of very frail material that the grinding machine stands out as vastly superior to other methods of grinding. In the study of caries of enamel in which disintegration has rendered the remaining tissue very frail and likely to fall to pieces before it is sufficiently thin, we may obtain the required thinness and yet retain all of the tissue. I have also produced exceedingly fine sections of salivary calculus, and equally good sections from small crumbs of serumal calculus. The production of these is slow, but fairly certain of good results.

Also in grinding sections of fossil teeth, fossil woods, and the like, in which very fine sections are too brittle to be handled in any way except as stuck to glass, the machine gives excellent results. In geological work it practically removes the difficulties. Good sections of the very brittle stones can be made with fair safety by grinding on the cover-glass.

Plans for Grinding Frail Material.—Much very desirable material for microscopic investigation will be found that is so frail, or at least so brittle, when reduced to sections thin enough for microscopic investigation, that it will crumble to pieces, either in the grinding or in the mounting, by the ordinary processes. For grinding and mounting such material the following processes have been slowly evolved. These may be divided into the balsam process and the shellac process. Such material that, when made fast to a cover-glass and ground in hard balsam, is not liable to go to pieces when this hard balsam is softened by sticking the specimen and glass cover to a glass slide may be ground in hard balsam. If, however, the different parts are liable to separate and change position when the balsam softens, shellac should be used for the grinding. I have had some very sorrowful failures in grinding rare specimens of enamel that had no cementing substance between the enamel rods in hardened balsam. For when the softer balsam was added to mount the specimen on the glass slide, the hard balsam was softened and the enamel rods floated out of position. All such material as will not hold together strongly enough to prevent this should be ground in shellac.

To grind in hard balsam, the one side of the specimen may be ground flat on the rough stone and then dried out in absolute alcohol. Then the ground side should be saturated to sufficient depth with soft balsam, and laid aside until the balsam has become hard enough to grind smoothly. Then the grinding and polishing of this first side should be completed by grinding away all balsam from the immediate surface, and sufficiently into the substance of the specimen to produce a clean, smooth surface of the material. When this has been done, and the surface dried, it should be mounted on an ordinary cover-glass, the thickness of which should have been measured and recorded. In this mounting the cover-glass should be laid on a spider and weight enough placed upon it to insure a perfect fit of the surface of the glass. This should be subjected to about 120° F. heat for from one to five or six hours, for the purpose of expressing the last bit of balsam possible from between the specimen and the cover-glass. Then it may rest, awaiting the convenience of the operator, for several days, but the balsam must not be allowed to become "brittle hard," because in that case it loses toughness. All excess of balsam about the margins of the specimen should be carefully removed to facilitate the hardening of that which remains, and especially so that it may not come in contact with the grinding stone, stick to its surface, and interfere with the cutting.

Good judgment must be acquired by practice as to the hardening of balsam and shellac in these grinding processes. *The best idea of it that can be given in words is this. The balsam or the shellac must have become firm enough so that it will not drag or allow the specimen to move while grinding in iced water. Neither must it become hard enough to become brittle, for then it becomes liable to break.*

When ready, the specimen is mounted on the grinding disk. This is done by first cleansing the disk, finishing with xylol, and then sealing the cover-glass to this with soft balsam. This should be placed on the spider and well weighted down with dogs. All excess of balsam should be carefully wiped away from the margins of the cover-glass. This may be quickly dried at 120° F., or more slowly at room temperature. It should, however, be warmed for a half-hour or more, for the purpose of expressing as much balsam as possible. This cover-glass will be well held for grinding in iced water with only a little drying about the margins, if all excess of balsam is cleaned away closely. The balsam should not become very hard.

If the specimen is of considerable bulk and of a quality of material that can be cut with a steel saw, the disk may be caught in a vise "with leather-cushioned jaws to avoid bruising," and the bulk of the material removed with a jeweler's saw, leaving only a moderately thin section for grinding. Or if the material is very hard, as stones, silicified fossils, etc., the disks may be mounted upon the slide rest and cut with the slicing disks, to be described later.

The specimen is now ready for the final grinding. The record for measurement with the particular stone to be used in finishing has been made, tried out on unimportant material, and the cover-glass has been measured and its record made. With this data, the disk is screwed to its place, the micrometer turned to the proper measurement for the finish, the iced water arranged, the machine set in motion, and it will do the rest. When coarser stones are used for cutting away considerable material, I find those with just a little experience prefer to gauge the amount of the cutting by the eye for the coarse stone.

Removal of the Cover-glass from the Disk.—I remove the cover-glass with the specimen from the grinding disk in two different ways, as seems at the time best.

First, the grinding disk is placed on a heated piece of metal that will warm the grinding disk quickly. Have a stick of rather soft wood ready, the end of which is cut to a rather sharp angle and thinned down almost in the form of a blade. When the grinding disk begins to warm, catch the margin of the cover-glass with the end of the stick and begin to make steady pressure. As the disk warms, so as to soften the balsam, the cover-glass will begin to move under the steady pressure, slowly at first, but more rapidly later, and will slide off the grinding disk before the specimen is loosened. For this plan the cover-glass should be pretty strong, one and one-half to two thousandths of an inch thick. Otherwise there will be great danger of breaking it. It is well in some cases to run just a little xylol around the margins of the cover-glass and partially dissolve the balsam that has become driest before the heating. Great care must be taken not to allow the xylol to spread on to the specimen, for it would loosen it very quickly.

The specimen is then turned downward and placed on a tiny drop of balsam on a glass slide, and quickly pressed down close and level. As the new balsam will soften the old, it should not be moved further than to quickly apply a light spring clip to hold it steady. The parts of the specimen are less likely to move if this is laid on ice for an hour or more.

The Use of Shellac.—In the second plan shellac is used instead of balsam for hardening the specimen and holding its parts together in the first grinding. This part of the work is otherwise done in the same way. The drying of the shellac requires more time usually than the balsam.

The attachment of the cover-glass to the grinding disk is done in the same way as when balsam is used to hold the specimen on the cover-glass—that is, with balsam. The grinding proceeds similarly in every respect.

In the removal of the cover-glass from the grinding disk, and mounting the specimen, comes the important differences in the two processes. Xylol dissolves balsam very quickly. But xylol does not dissolve shellac at all. Therefore, instead of pushing the cover-glass of the grinding disk, the disk is laid in xylol and the balsam dissolved out. In this there is no danger of detaching or moving the specimen if the handling is careful. When cleaned, it is inverted upon a glass slide on a drop of balsam without fear of movement of parts of the specimen, no matter how frail.

The Preparation of Shellac.—To keep shellac in condition for this work has some difficulties. The dry scales should be dissolved in absolute alcohol so as to make a moderately thick varnish. It should then be filtered at a temperature of 110° to 120° F., or be made thinner and filtered at room temperature. Great care should be exercised to keep the filtrate from exposure to a damp atmosphere, for it absorbs water readily and then will throw down fine crystals, which destroy its value for microscopic purposes.

After being filtered it should be evaporated in a close warming box in about 110° to 120° F., to the consistence of syrup. In doing this it is well to divide the supply into two or three grades—a thinner, medium, and a thicker solution. The thinner solution will be used for saturating frail specimens before any cutting is done. The thicker solutions for attaching specimens to the cover-glass for grinding. The medium solution for either purpose, as the material may seem to require.

The Grinding from Crumbled Material.—There is often important material for investigation that can be had only in very small crumbs, or broken pieces, such as serumal calculus, sands, crumbled bits of strange stones, or mixtures of such material as is found in some of the coarser sands. These, on microscopic investigation, may tell important stories as to their origin and throw important light upon geological questions. In addition to the ordinary microscopic observation, the polariscope may be turned on these, and reveal important facts as to their origin and structure. Also many things will be found in botanical work, such as obtaining sections of small seeds, and the like, which will give important information.

Having done a few of these grindings, especially of the very frail dental material, such as serumal calculus, extremely frail fossil teeth, etc., plans of work more or less well adapted have been developed.

For instance, I have obtained excellent sections of serumal calculus, which can be had only in small crumbs or flakes, in this wise: A small collection of these bits are first immersed for a time in absolute alcohol, or until all air has been removed if they are dry, or if they are freshly gathered, until all water has been removed. Then a cover-glass is prepared by covering its central part with the thicker solution of shellac, and these crumbs are placed in this, in what seems to be the best position for obtaining sections. These are allowed to soak full of the shellac, under a close cover, and then uncovered to dry up. Then, if some of the pieces seem to need it, more shellac is added from time to time, until the embedding seems sufficient. This may be dried at room temperature, or in the warming oven at 110° to 120° F. Shellac should not be subjected to much higher temperatures for a considerable time, because continued high temperature for many days together seems to injure the strength.

When this is sufficiently hard for smooth grinding, and before it has become too brittle (determining this point requires some experience), the preparation is cemented to the grinding disk with balsam and ground to such a point as seems most favorable for obtaining sections. This point is to be determined by frequent removal of the disk from the machine and examination of the exposed surfaces of the several pieces.

When this part is done, the cover-glass is dissolved off of the grinding disk by xylol. Then another cover-glass is attached to the surface *with the least possible amount of shellac.* This in turn is dried to the right consistence. Then the last cover-glass placed—that is, the one on the side that has been ground—is secured to the grinding disk with balsam. When this has set it is placed on the machine and the first cover-glass is ground away and the section ground to the required thinness. They are again dissolved off of the grinding disk, and may be at once mounted in balsam on the microscopic slide.

Difficulties in Grinding.—In the grinding of material enveloped in shellac, or in balsam, either of these materials are apt to gum up the stone and stop the cutting, or render the grinding very slow. When this is from balsam, it may be quickly removed after drying the stone by washing with xylol on a brush, or a bit of cloth, while the stone is slowly revolved.

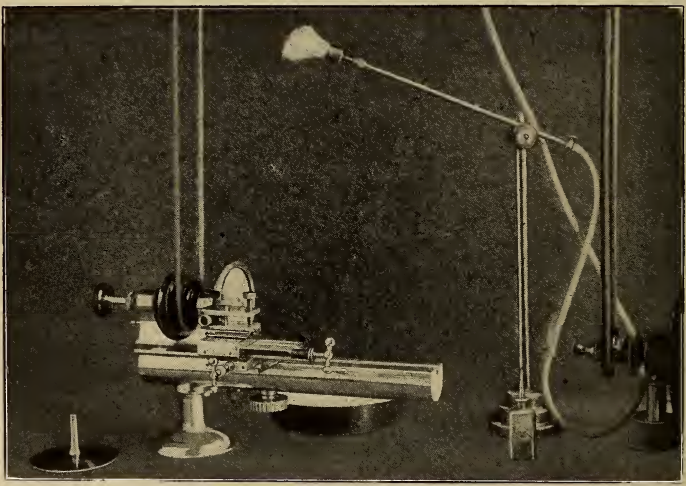
When clogged with shellac, the washing is done with absolute alcohol. This requires much more time, and some advantage may be obtained by using pumice stone with the cloth or with cork. After rubbing with pumice stone, a very thorough washing with alcohol should be made to remove the last particles of pumice, before rebeginning the grinding. Even with this, the ground surface is apt to be rough or scratched for a time by particles of the pumice lodged on the stone. These will soon disappear, however. Yet the pumice should not be used in the last portion of the grinding.

With much grinding of hard substances, the surfaces of the stones become worn so smooth that they do not cut well. Then the picking tool should be run over the surface until it is perceptibly roughened. This will cause the stone to cut briskly for a considerable time, and at first—following such sharpening—the ground surface of the specimen is likely to be full of scratches. In that case a smooth stone should be used for the finishing.

Much care should be taken in keeping the stones in good condition. Except in the ways mentioned, no dirt or grit should be allowed to come in contact with their surfaces. A single particle of grit lodged in the surface of the stone will fill the whole surface of the ground section with scratches. Although I shut up my stones in a close-fitting drawer, I find it necessary to cover each with a close-fitting cloth that is so closely woven as to exclude all dust.

In taking care of the machine itself, one cannot be too careful. All of the bearings of the lathe head and of the grinding machine should be swaddled with candle wick saturated with oil to prevent the ingress of gritty particles. This is especially needful when using the aluminum saws and feeding them with carborundum powder. Then every bearing about the whole machine should be especially protected to prevent the possibility of getting grit in the bearings. Carelessness in such a matter will quickly ruin a fine bit of mechanism. But with this care, such a machine should continue to do its work well for a lifetime (Figs. 341 and 342).

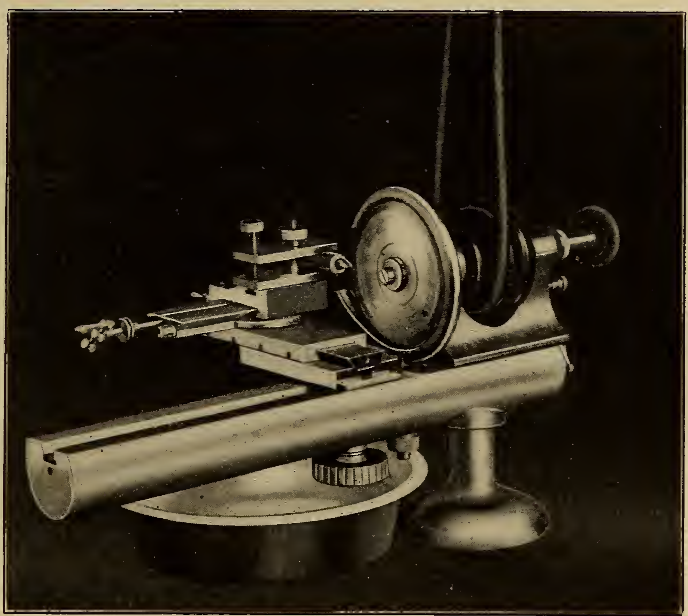
FIG. 341



FIGS. 341 and 342.—*Arrangement for slicing very hard material.* Fig. 341 is the more ordinary view of the machine with the slide rest and object holder in position. In Fig. 342 the lathe is turned about to give a better view of the slide rest, object holder, spatter guard, and aluminum disk. In these illustrations the slotted tube is used (see text) to hold the object being cut. Notice that the disk used for cutting is surrounded by a spatter guard which is open for a space at one side so that the periphery of the disk may be used in cutting. This guard gathers all water and grit used in cutting, and delivers it into the pan below through its hollow post. When doing this kind of work all of the bearings of the machine should be carefully wrapped (swaddled) to keep them safe from intrusion of grit.

The Slicing Mechanism.—This is an arrangement for slicing very hard substances which cannot be cut with the ordinary steel saw—such as the enamel of teeth, silicified fossils, rocks, etc. This consists of an aluminum disk fitted to the lathe head, and surrounded by a special form of spatter guard that admits of the use of the periphery for cutting, and an object holder fixed upon the slide rest of the lathe. The object holder consists of a clamp that grasps a brass tube slotted at the free end in which teeth, or other objects may be made fast with plaster of Paris or sealing wax for slicing. Or in place of this a brass mandril, upon the end of which there is a threaded nipple by which any of the grinding disks may be attached. These are fixed in the position of the ordinary tool post, and may be swung horizontally to any possible position in relation to the aluminum disk. An object can therefore be so placed on the disk as to be cut in any direction desired. Usually these are fixed upon the disk with sealing wax. In using the aluminum disk it is fed with carborundum powder suspended in soapy water to give it some stickiness. This is applied with a brush by hand, and is kept going so constantly as to prevent the disk from running dry. The ordinary aluminum plate, of twenty-

Fig. 342



four to thirty gauge, may be used for making these. They are first cut in circles by hand, as large as the lathe will swing (4 inches), and then are cut down to $3\frac{1}{2}$ inches with a tool in the slide rest. These are quickly made when wanted. They wear out rapidly, and yet one of them will do much cutting of very hard substances, and do it accurately and delicately. Rings may readily be cut from the ordinary test-tubes without special danger of breaking. The crown of a molar tooth may be cut into many slices; fossil teeth, silicified fossil woods, stones, etc., may readily be sliced as thin as they can be handled in the after-work of preparation.

APPENDIX CHAPTER II.

THE THEORY OF HISTOLOGICAL TECHNIQUE.

THE first requirement of histological technique is to obtain a general view of the theory of procedure. Many beginners make the mistake of supposing that directions for histological technique can be followed like the receipts of a cook book, or the directions for an experiment in chemistry. This is very seldom the case, and while it is always necessary to follow directions accurately, it is still more necessary to follow them intelligently. All histological methods require judgment. For instance, the length of time required for xylol to replace absolute alcohol in a block of tissue which is to be embedded depends upon the size of the piece, the character of the tissue, the temperature, and possibly some other factors. It is therefore impossible to say exactly what time would be required, and the experimenter must use the judgment which has been acquired as the result of experiment. In the same way no experimenter can make up a stain and be sure that it will work exactly like the last lot made by the same formula until he has tried it. Even with the same stain the length of time required for staining a section depends upon the thickness of the section, the character of the tissue, and the preliminary technique it has been through. So that all time directions must be considered as approximate, and to be successful the experimenter must study, first, the object to be obtained by the use of each reagent, and the peculiar action of the reagent upon the tissue.

For observation with the compound microscope transmitted light is ordinarily used. The object must therefore be thin and transparent enough to allow the light to pass through it. The higher the magnification the smaller the field, that is, the smaller the portion of the tissue that can be seen at one time, and the less depth of focus, and consequently the thinner the sections must be. A section that would be excellent for study with the $\frac{2}{3}$ objective may be almost valueless under a $\frac{1}{12}$, and sections that are splendid under the $\frac{1}{12}$ might be of little value under the $\frac{2}{3}$. In other words, the thickness of the section should be related to the magnification with which it is to be studied, and to the size of the structural elements which make up the tissue. For the study of the organs and tissues of multicellular organisms there are three general methods—(1) teasing, (2) maceration, and (3) sectioning.

Teasing.—In this method a small portion of the living tissue is torn apart with two needles in a drop of normal salt solution or some indifferent medium which will not affect the tissue. In this way it is spread into a thin film and squeezed a little between a slide and cover-glass so as to separate the structural elements when they may be directly observed. Of course, in studying such a preparation it must be remembered that the tissue has been forcibly torn apart and effects of violence must be looked for. These often bring out facts of structure which would not otherwise be as easily seen. After teasing the living tissue, staining agents may be used to facilitate the study of structure. The fresh tissues are often so transparent and made up of substances of so near the same refracting index that very little structure can be made out without the use of staining agents. It must be borne in mind that staining agents are of two classes, diffuse and selective. A diffuse stain gives an even color to all of the tissue and facilitates the study chiefly by rendering it less transparent. A selective stain combines more readily with one portion of the tissue than another, rendering it more conspicuous. Selective stains therefore must be thought of as chemical agents which combine with parts of the cell or tissue and demonstrate chemical differences in the structural elements. For instance, basic anilines react with the chromatin of the nucleus, producing a colored compound. The stain may then be washed out of the section, leaving only the nuclei colored. Acid anilines in general are diffusive stains giving a general color to the cytoplasm. In a similar way certain stains will react only or chiefly with intercellular substances, rendering them more conspicuous. For staining freshly teased specimens methyl green, the formula for which will be found under the paragraph on stains, is an excellent agent. Teased specimens are never very permanent, though they may be preserved for a considerable length of time by mounting in glycerin or glycerin jelly and putting a ring of varnish or white lead around the edge of the cover-glass so as to prevent evaporation.

Maceration.—When an organ is composed of more than one tissue the structural elements may be separated by selecting an agent which will act upon one and not upon the others; for instance, the muscle fibers of a voluntary muscle may be separated by treating a piece of tissue with dilute alkali, which will soften and dissolve the connective tissue, allowing the muscle fibers to separate. In a similar way dilute alcohol will soften the cementing substance between the epithelial cells. By first treating a piece of tissue with the proper agent and then teasing, the form of the structural elements of the tissue can be made out. By treating a portion of connective tissue containing both white and elastic fibers with dilute hydrochloric or acetic acid, which dissolves the white fibers, elastic fibers which could otherwise not be seen may be made out. Macerating and teasing methods are of great assistance to the study of tissues in sections, and it would be often very difficult to obtain true ideas of structure from sections without their assistance.

Sectioning.—For the study of the structural elements in their relation to each other in the tissue sectioning is the one method. As they exist in the body, however, some of the tissues are too soft and others too hard to allow the cutting of a thin enough slice without disturbing the relation of the structural elements. They must therefore be put through rather an elaborate process in which the object of every step must be understood.

Dissecting.—First of all, the material for histological work must be absolutely fresh, that is, living. It must be remembered that living cytoplasm is chemically different from dead cytoplasm, and as soon as death occurs postmortem changes begin which gradually destroy the structure. The period from death to the beginning of histological methods of preparation should be measured in minutes, not in hours. Tissues that have been dead for a few hours will not react with the staining agents so as to produce the brilliant specimens that can be obtained from fresh material, and often a few days will render material entirely useless except for the grosser anatomical relations. The specimens to be studied should be dissected while the cells of the tissue are still alive, and in doing so the greatest care should be used not to disturb the relation of the tissues.

Fixing.—Histologically this word means killing. After dissecting out the tissue to be studied, and while the cells are still alive, it must be immersed in some liquid that will kill the cells and *fix* their structure as when alive. The pieces should be made small enough for the fixing agent to penetrate them rapidly, and the size of the piece that can be used depends upon the density of the tissue, its character, and the nature of the reagent. Some fixing agents are very much more penetrating than others. All fixing agents coagulate or set the cytoplasm and tend to prevent shrinkage. The success of all the following steps and the value of the specimen for the study of detail of structure depend upon the perfection of fixation.

The fixing agents most commonly used are bichloride of mercury, potassium chromate or chromic acid, osmic acid, alcohol, and formalin. The formulas for the same will be found on pages 439 and 441.

Hardening.—Since all the fixing agents coagulate living cytoplasm, they are also to a greater or less extent hardening agents, and after fixing tissues may be handled with less danger of disturbing the relation of the structural elements. Some fixing agents, especially chromic fluids, may be continued in their action as hardening agents until the tissue has attained the proper consistency for sectioning, but, as a rule, it is necessary to use other agents for this purpose. In all cases the *fixing agent must be thoroughly washed out of the tissue* before the process is continued. Alcohol is the universal hardening agent, and at the same time it removes the water from the tissue. In carrying tissues from water to alcohol several grades must always be used, and the more delicate the tissue the more gradual must be the changes. If a piece of tissue is taken from water and placed in 95 per cent. alcohol, the diffusing currents will be so strong as to disturb structure and at the same time the hardening action is so energetic as to produce shrinkage. From water a tissue should never be placed in alcohol stronger than 70 per cent., where it should be allowed to remain for twenty-four hours. From 70 per cent. it may be taken to 95 per cent. for the same length of time, and from 95 per cent. to absolute, which will entirely remove the water and prepare the tissue for embedding. If the tissue is very delicate, it should be placed in water, then in 50 per cent. alcohol, and carried through in grades of 10 per cent. to 95 per cent.

Embedding.—In order to cut thin sections of tissue the piece must be surrounded and infiltrated with some firm substance which will not only support the entire piece, but will soak through the tissue, filling all intercellular spaces and supporting the individual structural elements. At the same time the embedding material is used to fasten the tissue firmly to a block of fiber or wood which can be grasped in the clamp of the sectioning machine. Two kinds of material are used for this purpose. Substances that are fluid when warm, and solid when cold, as paraffin, or substances which may be dissolved in volatile liquid and are solidified by evaporation, as celloidin. In both of these methods the substances, as a rule, are either oily or insoluble in water, and therefore the tissue must be thoroughly dehydrated—that is, have all the water removed from it before it is placed in the embedding material. To accomplish this there should be at least one change of absolute alcohol. From the absolute alcohol the tissue should be placed in a fluid which is a solvent for the embedding material, so that it will penetrate the tissue more perfectly and rapidly. Heat is always injurious to the tissue, and in embedding in paraffin, therefore, the tissue should be kept in the melted paraffin for the shortest possible time and paraffin of as low a melting-point as is consistent with sufficient hardness for cutting should be used. In embedding by evaporation the evaporation should not be too rapid or the shrinkage will be increased. Tissues may be kept blocked and ready to cut for a long time, but as a general principle the shorter the time the more perfect will be the specimen.

Sectioning.—For sectioning some sort of machine is necessary, and many kinds have been designed, the general principles of which are all the same. They consist of a clamp which holds the knife and a clamp which holds the specimen, and can be adjusted in such a way as to bring the specimen in proper relation to the knife. The position of the specimen is advanced by a micrometer screw so that sections of any desired thickness may be sliced. The delicate part of this machine is the micrometer screw. The essential to the success of its working is the sharpness of the razor, and for such specimens as decalcified bone the razor must be heavy and strong, so that the edge will not spring in cutting the hard tissue.

Staining.—The detail of staining process will be described in the next chapter, but it must be remembered that stains, as a rule, are water solutions and the sections must be carried through the grades of alcohol to water before they are ready for the stain. After staining they must be carried back through the grades of alcohol, so as to remove the water entirely before they can be mounted in balsam, which is not soluble in water.

Mounting.—Except in serial work, but one specimen should be placed on a slide, and this should be in the center, leaving room at either end for a label. In serial work the sections may be placed at one end of the slide, preferably the left hand, leaving room at the right for one label.

Labelling.—Nothing in histological technique is more important than labelling, especially in all research work. Through every step of the process the specimen must be kept track of, and a mixing of labels may spoil months of work. A laboratory note-book containing a record of all material and work should always be on the tables. I have found a system of date and number convenient. For instance, on June 4 a number of specimens are dissected out; in the note-book the record of the source of the tissue is made; the first piece is placed in a bottle of fixing fluid and the bottle labelled 6–4–1911, No. 1; the second, 6–4–1911, No. 2, and so on. In the note-book the description of each block and the date and the hour when it was placed in the fluid is recorded. In this way the tissue may be carried clear through recording each step in the process, and when it is sectioned and mounted we can follow its history in the note-book. Every slide should be labelled first with the date and the block number so as to follow its technique; second, the name of the tissue, and third, the kind of staining. This should be placed on the right-hand label, leaving the left-hand label for index and file number if the section is preserved.

Indexing and Filing.—Many beginners make the mistake of not indexing and filing their slides. They think because they have only a few, that they can easily find anything they want, and that they will wait until they have a larger number before they begin a system, but when a large number have piled up they can never find time to go back and arrange them as they should be. And only one who has failed in this way knows the annoyance of looking through hundreds of slides to find one that he knows he has some place.

APPENDIX CHAPTER III.

GENERAL HISTOLOGICAL METHODS.

Fixing.—As has been seen from the preceding chapter, fixing is the first and one of the most important steps in all histological methods. No degree of care in the latter steps can make up for any imperfection in it. As a general statement all fixing agents have advantages and disadvantages, so that in research work several should be tried and their results compared. For class-room work, however, minute details are not so important. Certain general principles may be stated. Bichloride of mercury is especially adapted to the fixing of epithelium of the mucous membrane. It, however, does not penetrate rapidly, and small pieces must be used. Crystals are liable to form in the tissue, and special precautions must be taken for their removal. Flemming's and Zenker's fluids and the fluids containing osmic acid are used chiefly in research. For class work the author uses Müller's fluid and Müller's fluid and formalin almost entirely. Stains are apt to work better after chromic fixing fluids. The formulas for several of the best fixing agents with directions for their use are found in the last chapter.

Washing.—Except for special purposes, fixing fluids are washed out of the tissues in running water, and they should be thoroughly removed. For this purpose the author has made a galvanized iron tank in which a gauze tray divided into small gauze compartments is suspended. The water is brought into the tank through a rubber tube with the mouth resting on the bottom, and leaves through a spout at the top to which another tube can be attached. In this way a large number of specimens can be washed at once and their identity followed.

Preserving Tissues.—After washing, the tissues should be carried through the grades of alcohol, and may be preserved for a considerable time in 80 per cent. alcohol, but it should be changed occasionally.

Choice of Sectioning Methods.—The choice between paraffin and celloidin for embedding depends upon the character of the section desired and the nature of the tissue. Small objects and those of delicate structure, such as embryos, dental pulps, etc., are best sectioned in paraffin. Large pieces and blocks containing tissues of different densities are more easily cut in celloidin. Paraffin can be cut much thinner than celloidin, and is therefore preferable for the minute study of cell structures with the high power. Celloidin sections are more easily stained and are easier handled and therefore preferable for the study of the arrangement of tissues with low powers. The author prefers celloidin sections for class work whenever possible.

Embedding in Paraffin.—Tissues fixed and washed are taken from 80 per cent. alcohol and placed in 95 per cent. for twenty-four hours, then in absolute alcohol for the same same length of time, and the absolute alcohol should be changed once during this period, from absolute alcohol to xylol, in which the tissue should remain until it is clear and translucent. The time in xylol should be as short as possible, as it has a hardening action. From xylol it is placed in a solution of paraffin in xylol, and from this to soft paraffin in the paraffin oven, at a temperature of not over 52° or 53° C. In this it should remain from one-half to six hours, when it is transferred to hard paraffin in the oven for the same length of time. The time in the oven should always be as short as is consistent with a perfect infiltration. After sufficient time in hard paraffin the tissue is blocked in the following way: A mold is made by placing L-shaped pieces of metal together on a flat slab. These are manufactured for the purpose. Melted paraffin is poured in the mold and the tissue arranged in it, placing it so that the sections will cut in the direction desired. A film of paraffin will harden at once on the slab and the tissue can be placed very nicely with the needles. As soon as a film has formed over the surface the slab with the mould should be immersed in cold water, so as to harden the paraffin as quickly as possible. When cold, sections may be cut at once or the block may be preserved in a pasteboard carton properly labelled. As a rule, paraffin sections should be cut as soon as possible.

Paraffin.—The paraffin for embedding tissues must be of the best quality. That prepared for this purpose by Grübler is preferable. It should be of two grades, that melting at 45° C., and that melting at 54° C. The hard paraffin is mixed with the softer, so as to give a melting-point at about 52°. In winter softer paraffin should be used than in summer, as the cutting quality depends upon the adjustment of the paraffin to the temperature of the room. If the paraffin is too hard the sections are liable to tear and curl; if it is too soft, the structure of the tissue will be disturbed in cutting. Perfect infiltration is always necessary for good sections. Chloroform or oil of cedar may be substituted for xylol in this process. Xylol is most rapid, but has some disadvantages in its action on the tissues, especially if left too long.

Cutting Paraffin Sections.—If the specimen has been placed at one end of the block, the other end of the paraffin may be clamped in the microtome. If the piece is too small, it should be fastened to a block of vulcanized fiber with melted paraffin and the fiber block clamped in the specimen holder. With a sharp scalpel the excess of paraffin around the specimen should be trimmed off, leaving the block in a rectangular form. The microtome knife is placed at right angles to the microtome bed, and the side of the block should be parallel with the blade. The specimen should be brought up just to the edge and the first section cut. The knife should be moved with a quick, sharp motion, as paraffin sections are chopped when the knife is in this position. The knife is pushed back, the block lifted with the micrometer screw so as to give a section of the proper thickness, and the second section cut. If the paraffin is of the proper consistency and the block has been properly trimmed, the edge of the second section will stick to the first and the sections stretch out over the knife in a ribbon. The ribbons may be transferred to a piece of clean white paper and complete series of sections cut. When series are not required larger specimens are often cut better by placing the blade of the knife obliquely and drawing it with a slow, even motion through the block. If the sections show a tendency to roll up when the corner of the section begins to curl over the edge of the knife, it may be caught with the tip of a camel's-hair brush and so section after section transferred to the paper. Paraffin sections should cut at a thickness of from seven to ten microns, but sections as thin as one micron may be cut from small blocks under ideal conditions.

Handling of Paraffin Sections.—For staining, paraffin sections must be fastened to the slide or cover-glass. If a few sections are to be cut the slide is preferable; if many sections, as in the preparation of class work, square cover-glasses should be used. In either case the glass must be absolutely clean. A stock of perfectly clean slides and cover-glasses should always be kept on hand (see p. 439). A thin film of albumin fixative is spread upon the glass; this film must be as thin as possible. The best way to spread it is to put a drop of fixative on a glass slab or an ordinary slide, touch the edge of the drop with the end of the little finger and spread it over the cover-glass, wiping off all that can be removed with the finger. Lay the cover-glasses film side up on a piece of paper until the required number have been prepared. As each section is cut it is laid on a cover-glass, straightened, and pressed down with a camel's-hair brush. If the sections curl or wrinkle they should be floated on water warmed just enough to soften the paraffin but not melt it. As each section is cut it should be dropped on the top of the water, where it will straighten out. When a number have been placed on the surface of the water they may be picked up by holding the cover-glass in the point of the pliers and slipping it underneath the section and lifting it as on a section

FIG. 343.—Morris staining dish.

lifter. The water is drained off and the cover-glass placed in the groove of the tray of a Morris staining dish,[1] shown in Fig. 343. Each tray will hold about thirty cover-glasses. They must now be thoroughly dried by leaving them over night at room temperature or for a shorter time in a warm oven, which should not be hot enough to melt the paraffin. When dry, each cover-glass should be picked up in the pliers and passed quickly through the middle of a Bunsen flame, so as to coagulate the albumin, or they may all be fixed at once in an oven. Heat that will just melt the paraffin will coagulate the albumin and hold the section on the glass. By means of a little wire basket the tray with the thirty cover-glasses may now be carried from one dish to another through the following necessary reagents. First, a minute or two in xylol to remove the paraffin; then absolute alcohol, then 70 per cent.; then water; Delafield's hematoxylin for five minutes; distilled water to wash off the stain; acid alcohol (70 per cent. alcohol to which 2 or 3 drops of hydrochloric acid has been added to every

[1] These are manufactured by Bausch & Lomb.

100 c.c. of alcohol); again washed in tap water to remove and neutralize the acid (some prefer alcohol to which a few drops of ammonia have been added); 70 per cent. alcohol; eosin for thirty seconds; 70 per cent. alcohol, then 95 per cent., then absolute, and finally xylol. From the xylol the sections may be mounted or given out to the class. For class work a student brings to the desk a clean slide with a drop of balsam on the centre and receives a section.

Summary of Paraffin Method.—

Tissues in 80 per cent. alcohol.
95 per cent. alcohol, twenty-four hours.
Absolute alcohol (changed once), twenty-four hours.
Xylol, one-half to six hours.
Xylol and paraffin, one-half hour.
Soft paraffin, one-half to six hours.
Hard paraffin, one to six hours.
Block.
Section.
Fix on glass.
Heat.
Xylol, one minute.
Absolute alcohol, one minute.
95 per cent. alcohol, same.
70 per cent. alcohol, same.
Distilled water.
Hematoxylin, five to ten minutes.
Tap water.
Acid alcohol.
Tap water or ammonia alcohol.
70 per cent. alcohol.
Eosin, thirty seconds.
70 per cent. alcohol.
95 per cent. alcohol.
Absolute alcohol.
Xylol.
Mount in balsam.
Label.

Celloidin Method.—Tissues fixed and washed are taken from 80 per cent. alcohol and placed in 95 per cent. for twenty-four hours; then in absolute alcohol for the same length of time, changing the alcohol once. Then into a mixture of absolute alcohol and ether for twenty-four hours, from this into a thin solution of celloidin, in which they should remain for from two days to a week. From the thin solution they should be placed in a thick celloidin solution, about the consistency of syrup, for the same length of time. The tissues may be kept in the celloidin solution indefinitely without injury, and if the tissue is difficult to infiltrate it may be of advantage to leave them in these solutions for weeks or months. In this case the bottles must of course be perfectly corked to prevent evaporation.

Blocking of Celloidin Material.—There are several methods for blocking celloidin materials, of which the author prefers the following: Thick celloidin is poured into a Stender dish or a small Petrie dish until there is enough to abundantly cover the specimens, which are arranged on the bottom of the dish. A match or bit of cork is placed under the edge of the cover so as to allow slow evaporation. In a day or two the celloidin will attain the consistence of a thick jelly. A knife is now passed around each tissue and the celloidin containing the specimen lifted out, and the excess of celloidin is trimmed away. A vulcanized fiber block has one surface dipped into the thick celloidin and the specimen arranged upon it. Thick celloidin is now added to surround and cover the tissue with its adherent celloidin. As soon as this is hardened so as to form a film it is dropped into 80 per cent. alcohol to harden the entire mass. In this it must remain at least twenty-four hours before it can be sectioned. Tissues embedded in celloidin may be kept for years in 80 per cent. alcohol blocked and ready to cut without great injury to the tissues.

Celloidin solutions for embedding should be kept in two grades and labelled "thick" and "thin" celloidin. The latter should be quite fluid, the former about a syrup consistence. Scherring's celloidin is furnished in two forms, in shreds and granules. The former will dissolve more rapidly. About half an ounce is placed in a large-mouthed bottle, and a mixture of equal parts of absolute alcohol and ether added. It dissolves slowly and should be shaken frequently. When this solution is sufficiently thick, part may be poured into another bottle and diluted with sufficient absolute alcohol and ether for the thin solution, while the thicker portion is poured into a bottle for the thick solution, and absolute alcohol and ether may be added to the stock bottle to dissolve the residue. When blocking tissues as described above the trimmings are dropped back into the stock bottle.

Cutting Celloidin Sections.—The fiber block is clamped in the specimen holder and adjusted. The knife is set diagonally so as to cut with a drawing motion, and both the knife and the block are kept flooded with 80 per cent. alcohol. The sections may be allowed to pile up on the knife, and after eight or ten are cut they are slid off with a camel's-hair brush on to a section lifter and transferred to 80 per cent. alcohol, in which they may be kept for some time.

Staining Celloidin Sections.—For transferring celloidin sections the most convenient thing is a small tea-strainer with a handle. These may be got for a few cents at any hardware store. By means of this the sections are transferred to 70 per cent. alcohol, from this to distilled water, and are stained from five to ten minutes in Delafield's hematoxylin. The stain is then washed off with tap water, destained with acid alcohol, washed in tap water or ammonia alcohol, stained thirty seconds in eosin, washed with 70 per cent. alcohol, from this to 95 per cent., in which they should be given two or three changes. From this they are transferred to beechwood creosote or some other clearing agent (see p. 445), and in this they may be kept until they are ready to mount or to be given out to the class. For class work the student brings to the desk a clean slide, and a section is placed upon the center of it. After blotting off the excess of oil he adds a drop of balsam, covers with a cover-glass, and labels the specimen.

Summary of Celloidin Method.—

Tissues in 80 per cent. alcohol.
95 per cent. alcohol, twenty-four hours.
Absolute alcohol, changed twice, twenty-four hours.
Absolute alcohol and ether, twenty-four hours.
Thin celloidin, two days to a week.
Thick celloidin, the same.
Evaporate.
Block.
80 per cent. alcohol to harden or store.
Sections cut in 80 per cent. alcohol.
70 per cent. alcohol, one minute.
Distilled water.
Hematoxylin, five to ten minutes.
Tap water.
Acid alcohol.
Tap water or ammonia alcohol.

70 per cent. alcohol.
Eosin, one miuute.
70 per cent. alcohol to wash.
95 per cent. alcohol, changed twice.
Creosote.
Mount in balsam.
Label.

Serial Sections with Celloidin.—It is difficult to cut series of sections with the celloidin method. The simplest process, and one used with success, is to carry the sections in order from the knife to the slide, arranging three or four at one end of it and leaving room for a label. Strips of porous tissue paper are cut the proper size and one laid over the sections to hold them in place. A thread is then lightly wrapped around the slide and paper, when they may be carried through the necessary agents for staining, in Naples jars. After they are cleared the paper is removed, the excess of the oil blotted off, the balsam put upon the section and covered with a long cover-glass.

SPECIAL METHODS.

Dental Pulp.—The unerupted premolars from a young sheep furnish excellent material for the study of the dental pulp. The jaws of sheep slaughtered for spring lamb can be easily obtained from the stockyards, and while still warm are placed in Müller's fluid and formalin, in which they are taken to the laboratory. The temporary incisors are still in place and may be used for peridental membrane material.

With the bone forceps the cortical plate is removed and the unerupted teeth dissected from their crypts. By grasping the base of the dental papillæ with the pliers the pulp may be pulled out of the dentin. They should then be replaced in Müller's fluid and formalin for twenty-four hours, when they may be carried through the usual process, embedded in paraffin, and sectioned.

Human Pulps.—By the coöperation of the extracting room human pulps for histological work may be obtained. As soon as extracted the tooth should be wrapped in a gauze napkin, placed in the jaws of a heavy vise, which is carefully tightened until the tooth cracks. The same thing may be accomplished by a heavy hammer on an anvil. A few trials of this will enable one to crack the tooth so that the pulps may be easily removed without injury. The cracked tooth is put in Müller's fluid and formalin for twenty-four hours, when the pieces of dentin are removed and the pulp carefully lifted out of the pulp chamber. It is then carried through the regular process, embedded in paraffin, and sectioned. If the teeth are not perfect clinical history should be noted.

Periosteum.—Young kittens that have not attained their full growth may be used for this purpose. The bone should be very carefully dissected so as not to injure the periosteum and then sawed in pieces, using a fine metal saw. It is usually best simply to saw it in two at the middle of the shaft and to fix it in Müller's fluid and formalin. After fixing and washing, it should be cut in small pieces and decalcified in 2 to 5 per cent. nitric acid. A comparatively large volume of acid should be used and a pad of cotton placed in the lower half of the bottle, or the tissue suspended by a thread. It is best to change the acid once a day. Decalcification may require from two days to a week, and should be tested by passing sharp needles through the tissues. As soon as decalcified the tissue should be washed for twenty-four hours in running water, carried through the grades of alcohol, and embedded in celloidin. The sections should be cut at right angles to the shaft.

Peridental Membrane.—For class work the peridental membranes of sheep are the best for study, as their fibers are large and their direction easily observed. They are much better than those of either cat or dog, in which the fibers are much finer and the bone more dense. The jaws are brought from the stockyards in Müller's fluid and formalin, the crowns broken off at the level of the gum so as to expose the pulp chamber, and the jaws sawed through so as to leave two teeth in each block, after which they are replaced in Müller's fluid and formalin for two days, decalcified in nitric acid, and thoroughly washed. They may now be cut into small blocks for transverse sections and embedded in celloidin.

Embryological Material.—For the study of the tooth germ in class work embryo pigs of all ages are easily obtained. The entire embryo should be at once placed in Müller's fluid or a saturated solution of picric acid and water. In Müller's fluid they should remain a week; in picric acid, forty-eight hours. After fixing, the heads are cut off, thoroughly washed, carried through the grades of alcohol, and embedded in paraffin.

APPENDIX CHAPTER IV.

FIXING AGENTS AND STAINING SOLUTIONS.

Cleaning of Slides and Cover-glasses.—Slides or cover-glasses on which paraffin sections are to be mounted must be absolutely clean. They should be dropped in strong sulphuric acid and allowed to remain a few minutes. The acid should then be poured off and thoroughly removed with water, and strong acetic acid poured on. After remaining a few minutes wash the acid off thoroughly and wipe from alcohol. Keep ready for use in a clean box.

Meyer's Fixative.—The white of an egg is chopped with a pair of scissors and filtered through muslin, diluted with an equal volume of glycerin, and a little sodium oxalate added to prevent decomposition.

FIXING AGENTS.

Flemming's Solution.—A good solution for fixing nuclear structures is the chromic acid solution of Flemming:

	Parts.
Osmic acid, 1 per cent. aqueous solution	10
Chromic acid, 1 per cent. aqueous solution	25
Glacial acetic acid, 1 per cent. aqueous solution	10
Distilled water	55

Small pieces are fixed in a small quantity of the fluid for at least twenty-four hours. They are then washed for the same number of hours in running water and passed through 50, 75, and 80 per cent. each twenty-four hours into 90 per cent. alcohol.

A stronger solution is made as follows:

	Parts.
Osmic acid, 2 per cent. aqueous solution	4
Chromic acid, 1 per cent. aqueous solution	15
Glacial acetic acid	1

Fol's Solution.—A modification of Flemming's solution.

	Parts.
Osmic acid, 1 per cent. aqueous solution	2
Chromic acid, 1 per cent. aqueous solution	25
Glacial acetic acid, 2 per cent. aqueous solution	5
Distilled water	68

Corrosive Sublimate.—An excellent fixing fluid is made by saturating distilled water with corrosive sublimate. Small pieces about 0.5 cm. in diameter are immersed in this fluid for from three to twenty-four hours, then washed in running water for twenty-four hours, and then transferred into 70 per cent. alcohol. After twenty-four hours the tissues are placed in 80 per cent. for the same length of time and then preserved in 90 per cent. It often occurs that after changes in temperature crystals of sublimate are formed on the surface or in the interior of the object. For their removal a few drops of iodine and potassium iodide are added to the alcohol (P. Mayer). It is a matter of indifference whether the 70 per cent., 80 per cent., or 90 per cent. alcohol is thus iodized. In future treatment of the object, as well as in sectioning, any such crystals of sublimate will not be found to be a hindrance. In the case of delicate objects it is better to undertake their removal *after* sectioning by adding iodine to the absolute alcohol then used.

Acetic Sublimate Solution.—An excellent solution specially used for embryonic tissues and for organs containing only a small quantity of connective tissue. To a saturated aqueous solution of sublimate, 5 to 10 per cent. of glacial acetic acid is added. After remaining two to three hours or more in this solution, the objects are transferred to 35 per cent. alcohol and then passed through the higher grades of alcohol.

Picric Acid.—Small and medium-sized objects (up to 1 c.c.) are fixed in twenty-four hours in a saturated aqueous solution of picric acid (about 0.75 per cent.). Objects of considerable size may be left in this solution for weeks without detriment. The tissues are then transferred to 70 or 80 per cent. alcohol, in which they remain until the alcohol is not colored by the picric acid. Instead of a pure solution of picric acid, the picrosulphuric acid of Kleinenberg, or the picric acid of P. Mayer may be used. Picrosulphuric acid is made as follows: 1 c.c. of concentrated sulphuric acid is added to 100 c.c. of a saturated aqueous picric acid solution. Allow this to stand for twenty-four hours and dilute with double its volume of distilled water. The picric acid solution is made by adding 2 c.c. of pure nitric acid to 100 c.c. of saturated picric acid solution. Filter after standing for twenty-four hours.

Chromic Acid.—Chromic acid is used in a $\frac{1}{3}$ to 1 per cent. aqueous solution. Small pieces are fixed for twenty-four hours, larger ones for a longer time. The quantity of the fixing fluid should equal at least more than fifty times the volume of the tissues to be fixed.

After fixing, objects must be washed for at least twenty-four hours in running water, then through the grades of alcohols, and preserved in 80 per cent. Two to 3 drops of formic acid to every 100 c.c. of chromic acid solution improve their fixing properties.

Müller's Fluid.—

Potassium bichromate	2 to 2.5 grams
Sodium sulphate	1 gram
Water	100 c.c.

This solution requires a long time for fixing, at least several weeks, and for large pieces several months. During the first few weeks the solution should be changed every three or four days and later once a week, until it remains clear. Tissues should be thoroughly washed in running water at least twenty-four hours. For some special purposes it is better to wash in alcohol. Tissues should be carried through the grades and preserved in 80 per cent. alcohol. While tissues are in Müller's fluid they should be kept in the dark.

Müller's Fluid and Formalin.—

Müller's fluid	100 c.c.
Formalin	10 c.c.

The addition of formalin to Müller's fluid greatly hastens fixation. It is an excellent agent of great penetrating power, and tissues stain very well after it. Twenty-four hours will fix tissues of ordinary size, though they may be left longer without damage. Bone fixed too long in formalin is liable to be hard to cut.

Zenker's Fluid.—

	Grams.
Potassium bichromate	2.5
Sodium sulphate	1.0
Corrosive sublimate	5.0
Glacial acetic acid	5.0
Water	100.0

Add the glacial acid in proper proportion to the quantity of the solution to be used, and not to the stock solution. Allow the tissues to remain in this solution for from six to twenty-four hours. Then wash in running water for from twelve to twenty-four hours and transfer to gradually concentrated alcohol. Crystals of sublimate which may be present are removed with iodized alcohol. Zenker's fluid penetrates easily and fixes nuclear and protoplasmic structures equally well without decreasing the staining qualities of the elements.

Formalin.—Of recent years formalin, which is a 4 per cent. solution of the gas formaldehyde in water, has been much used as a fixing fluid. Make a solution by adding 10 parts of formalin to 90 parts of water or normal saline solution. Small pieces of tissue should remain in this for from twelve to twenty-four hours, larger pieces a number of days or weeks, and then transfer to 90 per cent. alcohol.

STAINING AGENTS.

Delafield's Hematoxylin.—

Hematoxylin crystals	4 grams
Absolute alcohol	25 c.c.
Ammonia alum, aqueous solution	400 c.c.
Methyl alcohol	100 c.c.
Glycerin	100 c.c.

Dissolve hematoxylin crystals in absolute alcohol and add to the alum solution, place in an open vessel for four days, then filter and add the methyl alcohol and glycerin.

Hemalum (Mayer, 91).—One gram of hematin is dissolved by heating in 50 c.c. of absolute alcohol. This is poured into a solution of 50 grams of alum in 1 liter of distilled water and the whole well stirred. A thymol crystal is added to prevent the growth of fungus. The advantages of hemalum is as follows: The stain may be used immediately after its preparation, it stains quickly, never overstaining, especially when diluted with water, and penetrates deeply, making it useful for staining in bulk. After staining sections or tissues are washed in distilled water.

Safranin.—

Safranin	1 gram
Absolute alcohol	10 c.c.
Aniline water	90 c.c.

Aniline water is prepared by shaking up 5 c.c. to 8 c.c. of aniline oil in 100 c.c. of distilled water and filtered through a wet filter. Dissolve the safranin in the aniline water and add the alcohol. Filter before using.

Stain sections fixed in Flemming's solution for twenty-four hours and decolorize with a weak solution of hydrochloric acid in absolute alcohol (1 to 1000). After a varying period of time, usually only a few minutes, all the tissue elements will be found to have become bleached, only the chromatin of the nucleus retaining the color.

Methyl Green.—Stains very quickly. One gram is dissolved in 100 c.c. of distilled water to which 25 c.c. of absolute alcohol is added. Rinse the sections in water, then place in 70 per cent. alcohol for a few minutes, transfer to absolute alcohol for a minute, etc.

Hematoxylin.—Van Gieson's Acid Fuchsin-Picric Acid Solution.—Stain in any of the hematoxylin solutions, and after rinsing sections in water counter-stain in the following:

Acid fuchsin, 1 per cent. aqueous solution	5 c.c.
Picric acid, saturated aqueous solution	100 c.c.

Dilute with an equal quantity of water before using. The hematoxylin stained sections remain in the solution from one to two minutes, are then rinsed in water, dehydrated, and cleared.

Hematoxylin-Eosin.—Sections already stained in hematoxylin are placed for two to five minutes in a 1 to 2 per cent. aqueous solution of eosin or in a 1 per cent. solution of eosin in a 60 per cent. solution of alcohol. They are then washed in water until free from the stain, after which they remain for a short time in absolute alcohol. In place of the eosin solution a 1 per cent. aqueous solution of benzopurpurin may be used for the following solution of erythrosin (Held).

Erythrosin	1 gram
Distilled water	150 c.c.
Glacial acetic acid	3 drops

Silver Nitrate Method.—Especially useful for staining intercellular substances of epithelium, endothelium, and mesothelium, and the ground substance of connective tissues. It may be used on either fresh or fixed tissues, fresh tissue, however, being more satisfactory. Spread the tissues to be stained in thin layers; immerse in a 0.5 to 1 per cent. solution of silver nitrate from ten to fifteen minutes; rinse in distilled water and place in fresh distilled water or 70 per cent. alcohol or a 4 per cent. solution of formalin and expose to direct sunlight until they assume a brown color. The sunlight reduces the silver in the form of fine particles which appear black on being examined with transmitted light. The preparations thus obtained may be examined in glycerin or dehydrated and mounted in balsam.

Glycerin.—To mount in glycerin transfer the sections from water to the slide, cover with a drop of glycerin, and apply the cover-slip.

Sections colored with a stain that would be injured by contact with alcohol and where clearing is not especially necessary are mounted this way.

Farrant's Gum Glycerin.—In place of pure glycerin the following mixture may be used:

Glycerin	50 c.c.
Water	50 c.c.
Gum arabic (powder)	50 grams
Arsenous acid	1 gram

Dissolve the arsenous acid in water. Place the gum arabic in a glass mortar and mix it with the water, then add the glycerin. Filter through a wet filter paper or through fine muslin. To preserve such preparations for any length of time the cover-glasses must be so fixed as to shut off the glycerin from the air. For this purpose cements or varnishes are used, by painting over the edges of the cover-glass. These masses adhere to the glass, harden, and fasten the cover-glass firmly to the slide, hermetically sealing the object. Krönig's is one of the best formulas for varnish, and is made as follows: Melt 2 parts of wax and stir in 7 to 9 parts of colophonium and filter the mass hot. Before employing an oil immersion lens it is best to paint the edges with an alcoholic solution of shellac.

Silver Nitrate.—In thin membranes and sections the vessel walls can be rendered distinct by silver impregnation, which brings out the outlines of their endothelial cells. This may be done either by injecting the vessel with a 1 per cent. solution of silver nitrate, or with a 0.25 per cent. solution of silver nitrate in gelatin. This method is of advantage, since after hardening the capillaries of the injected tissues appear slightly distended. Organs thus treated can be sectioned, but the endothelial mosaic of the vessels does not appear definitely until the sections have been exposed to sunlight.

The injections of lymph channels, lymph vessels, and lymph spaces is usually done by puncture. A pointed cannula is thrust into the tissue and the syringe empties by a slight but constant pressure. The injected fluid spreads by means of the channels offering the least resistance. For this purpose it is best to use aqueous solution of Berlin blue or silver nitrate, as the thicker gelatin solutions cause tearing of the tissues.

Clearing Agents.—Clearing agents are substances of high refracting index, mostly oils, which are used to displace alcohol and prepare tissues for embedding and sections for mounting in balsam.

Clearing agents for embedding in paraffin must be miscible with alcohol and solvents for paraffin. They are called clearing agents because the tissues become translucent and clear in them. Xylol is the most rapid and probably most used agent. It has, however, a hardening action on the tissues, especially if they remain too long in it. Pure oil of cedarwood when free from turpentine is an excellent agent. Chloroform has been largely used for the same purpose.

Before celloidin sections are mounted in balsam they must be cleared. For this purpose an oil that will mix with 95 per cent. alcohol is desirable, as absolute alcohol softens the celloidin. The oil used must not dissolve the celloidin, and should not dissolve the stain. Beechwood creosote is an excellent agent, and has been largely used. It clears sections rapidly from 95 per cent. alcohol. Oil of bergamot is an excellent agent, also oil of origanum; but in the latter the oleum origani cretici and not the oleum origani gallici must be used. A mixture of equal parts of oil of bergamot and beechwood creosote has been used satisfactorily, and is an excellent agent. A cheaper mixture is made of equal parts of phenol, oil of origanum, and oil of cedarwood.

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